ACTA ORTHOPEDICA SCANDINAVICA
SUPPLEMENTUM no 61

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*FROM THE DEPARTMENT OF SURGERY, MARIA HOSPITAL,
HELSINKI (HEAD PROFESSOR P. I. TUOMINEN, M.D.)*

ADRENALECTOMY OR AMPUTATION? EXPERIENCES IN THE TREATMENT OF PERIPHERAL ARTERIOSCLEROTIC GANGRENE

BY

TEUVO K. I. LARMI

MUNKSGAARD
COPENHAGEN 1963

Suomalaisen Kirjallisuuden Kirjapaino Oy Helsinki 1963

INTRODUCTION

The surgery of the peripheral arteries was widely discussed at the 29th meeting of The Scandinavian Surgigal Society held in Helsinki 1959 Arterial resection by pass operation or thromboendarterectomy were the procedures of choice but when the arterial occlusion was peripheral or multiple sympathectomy or amputation were the only possibilities If sympathectomy was performed early enough and the high lumbar technique described by SEIRO (1955) was used it was possible to postpone amputation and reduce the frequency of higher amputations (HOLOPAINEN 1959) Claudication however was usually left unchanged thus indicating that it was mainly the skin circulation and not that of the muscles that improved after sympathectomy

On the other hand it is known that the increase of blood flow obtained immediately after sympathectomy gradually diminishes (literature reviewed by BARCROFT and SWAN 1952) This may be due to a) the arteries becoming supersensitive to circulating adrenaline b) their supersensitivity to an unknown hormone or c) a direct effect on the contractile process of intrinsic changes in the smooth muscle According to DUFF (1952) the skin vessels especially very readily contract in response to adrenaline Could use be made of this observation in the treatment of impending arteriosclerotic gangrene by performing adrenalectomy?

OPPEL (1922) was the first to perform unilateral adrenalectomy for the treatment of a patient with Raynaud s disease His result was poor but since then LERICHE and after him by many other authors have published their experiences of adrenalectomy or adrenomedullectomy - some of these bilateral — in the treatment of periperal vascular diseases (e g DURANTE 1952 KISS DEGRFIL, SINKO and KUDÁSZ 1954 SERVELLE, ROUGEULLE and

DELAHAUE 1954) In Scandinavia only BOGGILD (1948) and PAABY and NORING (1956) have presented their results on some patients treated by adrenalectomy for Raynaud s or Burger s disease In the latter series there was also one case of arterio sclerotic occlusion

The author of the present paper came to perform his first adren alectomies under circumstances where the condition of the arteries precluded any reconstructive operations where in most cases sympathectomy had already been performed and where impending arteriosclerotic gangrene demanded prompt action, but the patients refused amputation The purpose of this paper is to present the authors experiences obtained with ten patients in all of whom peripheral arteriosclerotic gangrene was treated by unilateral adrenalectomy

PRESENT SERIES

The present series consists of ten patients aged 51–72 years. The oldest patient was a woman, the others men. The duration of symptoms before adrenalectomy, mainly aching and claudication, was 3/4–10 years. In addition to arteriosclerosis patient No. 8 probably also has Burgers disease: this was suggested by histological examination of an artery from the amputated leg. All the patients had rather advanced generalized arteriosclerosis. One patient (No. 2) had had myocardial infarction twice, another (No. 3) once before adrenalectomy. The severity of the arteriosclerotic changes in the present series is also indicated by the fact that in case No. 8 the right thigh had been amputated two years and in case No. 10 the left II–V toes removed seven years before adrenalectomy.

Gangrene in toes or foot was evident in all ten cases. Infection or necrosis was seen in eight patients and four of them had osteitis of one toe bone. Of course there was no question of attempting to cure the bone infection by adrenalectomy but only of getting more rapid demarcation and thus reducing the length of leg to be amputated. The extremely poor condition of the patients is seen from figures 1 and 2, which show the extent of the necrosis.

Preoperative angiographic studies — omitted only in case No. 1 — showed that either the arteriosclerotic occlusion was situated very distally or the sclerotic changes or complete occlusion were so widespread that reconstructive surgery was out of the question (Table 1, Figs. 3, 4 and 5).



Fig 1

Fig 1 The left foot is swollen and all the toes suppurating in case 8 Osteitis in the great toe



Fig 2

Fig 2 The left 1st—3rd toes blue with osteitis in the great toe in case 10 The 2nd—5th toes partially amputated after sympathectomy seven years before adrenalectomy





Fig 4



Fig 5

Fig 3 Angiogram of the femoral and popliteal arteries on the right side in case 4 showing arteriosclerotic plaques in the lower part of the femoral artery and in the popliteal artery and complete block in the mid-calf

Fig 4 Angiogram of the femoral and popliteal arteries on the left side in case 6 showing severe arteriosclerotic changes in the femoral artery The popliteal artery is fairly smooth but there is [illegible] occlusion in the middle of the [illegible]

Fig 5 Angiogram of the femoral and popliteal arteries on the [illegible] side in case 8 Arteriosclerotic changes in the femoral artery [illegible] middle of the thigh where occlusion be[illegible] [illegible] the knee only a few

OPERATIVE TECHNIQUE AND POSTOPERATIVE MANAGEMENT

Operations were performed using the muscle splitting incision originally described by SEIRO for high lumbar sympathectomy The peritoneum was kept intact and pushed away so that the crura of the diaphragm came into view and the side faces of the lumbar vertebrae could be felt medially down to the fifth vertebra By dissection through the fat pad close to the upper pole of the kidney the whole adrenal gland and its vessels were exposed The vessels were tied with one or two silk ligatures (Fig 6) and the adrenal gland was then removed intact

As is seen in table 1 in six cases lumbar sympathectomy had been performed two months to nine years before adrenalectomy In four patients it was done simultaneously with adrenalectomy To be able to control the completeness of the previous sympathectomy, adrenalectomy was in all cases performed on the side where the gangrene was During the operation immediately after removal of the gland 25—100 mg of hydrocortisone was injected intravenously The dose of hydrocortisone was determined according to the amount of the blood pressure drop, which was never very significant On the day of operation no other substitution therapy was necessary On the first day after operation 50—150 mg of hydrocortisone was given and this dose was then gradually reduced during the following days and completely discontinued after a week The postoperative course was uneventful in all cases



Fig 6 Operatis field n adr nal ct my perform d thr b bi h lumbar sympathe t my n isson by SEIRO No e good r w and li ature round suprarena l artery

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Fi 6 Operat ve field in adr nalectomy performed thro ı h high lumbar sympathect my ncis on by SPIRO *Note good view a d ligatu e round suprare al artery*



RESULTS

The condition of the leg immediately after operation looked favourable in nine cases Preoperative pain got easier oedema disappeared in a week or two and in those patients who later had amputation of a toe, demarcation appeared in a week Only one patient (No 2) did not even experience transient improvement Gangrene was getting worse and amputation at the level of the thigh had to be done ten days after adrenalectomy Two other patients made favourable progress for a week but then the pain returned and the gangrene which had seemed to be arrested began to progress again One of these patients had thigh amputation two weeks the other lower leg amputation three weeks after adrenalectomy (Table 1) The latter patient had osteitis in his big toe

Postoperative improvement could also be confirmed by angiography An example is the 56 year old man (case 5) in whom in addition to occlusion of the peripheral arteries, the so-called interference phenomenon was observed in arteriograms before operation After the injection of the contrast material the lumen of the popliteal artery was seen to have the form of a pearl necklace (Fig 7) a picture which appears in connection with great peripheral resistance (THEANDER 1960) On postoperative angiograms this interference phenomenon was not present the flow of the contrast material was more rapid and the peripheral vessels could be seen better than before adrenalectomy (Fig 8)

Follow up studies showed that the patient who had the longest observation period (3 1/2 years) was able to start physical labour 1 1/2 months after adrenalectomy At the time of writing he is still able to do the same work He has some calf pain from time to time but no infection Four other patients report that they started work

TABLE 1 *Present series of 10 patients with peripheral arteriosclerotic gangrene surgical*

Case	Sex Age	Duration of symptoms before adrenalectomy (years)	Gangrene	Angiography	Sympathectomy	Adrenalectomy
1 V J[1]	M 56	3/4	The right foot swollen Necrotic ulcer in the sole	Not performed	August 1958	8 10 58
2 A L[1]	M 63	1 1/4	Necrotic ulcer on the lateral side of the right tibial malleolus	Complete obliteration from the common iliac artery to the middle leg	February 1959	19 8 59
3 F V	M 60	5	Right great toe suppuration for two years Osteitis in the distal phalanx	Complete obliteration from the femoral artery to the lower part of the leg	1955	18 1 61
4 U P	M 51	1 1/2	The right great toe suppurating	Arteriosclerotic changes distally from the popliteal artery (Fig 3)	May 1960	23 3 61
5 K K	M 56	3	The right foot and toes swollen the nail of the great toe dark	Arteriosclerotic changes from the femoral artery to the periphery Interference phenomenon (Figs 7 and 8)	19 4 61	19 4 61
6 R R	M 57	10	The whole foot pale cold and aching	Arteriosclerotic changes from the *femoral artery to the* periphery Complete obliteration in the mid-calf (Fig 4)	27 4 61	27 4 61
7 R T	M 56	1 1/4	Necrotic suppurative ulcer on the lateral side of the sole	Arteriosclerotic changes from the femoral artery to the mid-calf	12 5 61	12 5 61
8 V R	M 52	10	The left foot swollen All toes blue swollen and suppurating Osteitis of the great toe (Fig 1)	Complete obliteration from the femoral artery to the mid calf (Fig 5)	1952	17 5 61
9 M L	F 72	1 1/4	Suppuration of the 3rd and 4th toes for 4 months Osteitis in the 4th toe	Complete obliteration from the common iliac artery to the popliteal artery	19 5 61	19 5 61
10 A H	M 60	7	The 1st to 3rd toes blue on the left side The skin of the great toe black (Fig 2) Osteitis of that toe	Lumen of the arteries patent until the lower leg Peripheral block	1954	2 12 61

[1] Operated at Valkeakoski Hospital Valkeakoski

Prima y Results	Amputation	Late Results	Follow up tim (y rs)	Rema k
Oedema and aching disappeared. Gangrene diminished.	— —	Able to work from 15 11 58 Occasional pain No necrosis or suppuration	3 1/2	—
Not better	Femoral 29 8 59	Arteriosclerotic ne crosis of the foot on the left side leading to femoral amputation 1961	3 1/4	Myocardial infarction twice before adrenal ectomy
Pain disappeared for a week thereafter a recurrence	Below knee 9 2 61	Stump clean	1 1/2	Myocardial infarction once before adrenal ectomy
Pain disappeared in a week and suppuration in two weeks	—	Able to work from 25 5 61 on No symptoms	1 1 2	
Pain disappeared im mediately oedema in a week	—	Able to work from 1 6 61 on Occasional pain. Right ankle moderately swollen	1 1/2	Pulmonary tubercu losis
Aching and pain dis appeared in a week and flesh colour re appeared	—	Claudication after 30—50 metre s walk	1 1/2	Pulmonary tubercu losis and emphysema Peptic ulcer of the stomach
Suppuration and ten derness gradually di minished Recurrence after half a year	5th meta tarsal bone 4 5 62	Wound clean but foot tender Not yet at work	1 1/4	
Better for a week then recurrence	Femoral 30 5 61	Stump clean	1 1/4	Right femoral ampu tation in 1959 for ar teriosclerotic gan grene Burger s dis ease Severe pulmo nary emphysema
Pain disappeared, gangrene became dry and demarcation was accelerated.	4th toe 2 11 61	Able to walk 1/2 km without stop No sup puration or necrosis Occasional pain	1 3/4	Pain reappeared in autumn 1961
Oedema and pain dis appeared in a week Demarcation was ac celerated	The distal part of the great toe 9 1 62	Able to work from 12 3 62 on	3/4	The 2nd—5th toes partially amputated in 1954 for arterio-sclerotic gangrene and frostbite



Fig 7



Fig 8

Figs 7 and 8 Demonstration of the effect of adrenalectomy by angiograms Fig 7 which was taken before adrenalectomy shows a typical interference phenomenon in the right popliteal artery the wall of which resembles a pearl necklace The vessels distally of the popliteal artery are not well seen Fig 8 was taken after adrenalectomy the interference phenomenon is no longer present and the peripheral vessels are better visualized

about two months after the operation Patient No 4 is completely without symptoms Two patients affirm that they have only occasional aches in their legs and feet; in one case the main trouble is claudication pain occurring after 50 metre s walk and in winter even sooner

In cases 9 and 10 amputation of one toe was performed six months and one month respectively after adrenalectomy Both had osteitis in the toes subjected to amputation The former patient owing to her age — 72 years — is no longer at work but she is able to walk half a kilometre without resting After toe amputation she no longer has infection but sometimes legache The latter patient has been doing manual work for more than half a year and has no symptoms In case No 7 bone infection and pain reappeared 6 months after adrenalectomy Half a year later amputation of the fifth metatarsal bone was performed The wound is now 1 1/2 months after the procedure completely healed and there is no infection or aching but the foot is still painful on walking and the patient has not yet returned to work.

DISCUSSION

Peripheral arteriosclerotic gangrene is a thankless task for the surgeon Thanklessness, however is by no means typical of the individual patient In the present series all the patients — even those who later lost their legs — were appreciative of the endeavour made to avoid amputation

Statistically the results of adrenalectomy or adrenomedullectomy are not very good Comparison between the present series and earlier results is difficult because adrenalectomy has usually been used in the treatment of Burger's or Raynaud's disease In DURANTE's material — most of the patients were under 50 years of age — there were 68 pregangrenous and 123 gangrenous cases In 42 of these gangrene reappeared after adrenomedullectomy SERVELLE et al performed 43 adrenalectomies but in all cases sympathectomy and splanchnicotomy were also done All patients were under the age of 50 Amputation was avoided in many cases and the authors also make the following statement »Nous avons plusieurs cas de ce gengre ou la surrenalectomie nous a permis des amputations d orteils ou d avant pied »

It is difficult or quite impossible as PYABY and NORING point out to estimate the differential effect of adrenalectomy and sympathectomy when they are performed simultaneously In some cases of the present series amputation was avoided even when sympathectomy had been performed previously KRIMER (1959) says in his monograph that »alleinige Nebennierenoperationen ohne Sympathektomien sind sinnlos» However the author of the present paper has seen a patient with impending arteriosclerotic gangrene who was operated on by SEIRO and adrenalectomy was

the only measure undertaken (unpublished) The effects of the operation were about the same as after sympathectomy, — pain and oedema disappeared From the monograph by SIVULA (1961) it is evident that the connection between the adrenal hormones and peripheral arteries is still not completely understood even in health and still less in pathological conditions For example, the effect of noradrenaline on the peripheral vessels of a healthy man may be constriction dilatation or failure to react at all

Adrenalectomy as a treatment for thromboangiitis has been defended on the ground that there must be some kind of functional hyperactivity and hyperplasia of the adrenal glands in these cases (TIGAUD and CARLES 1952) In the present series of arteriosclerotic patients all the glands removed were examined histologically but nothing abnormal was found FERRAND and ELBAZ (1957) claim on theoretical grounds that hyalinosis and arterial *constriction induced by mineralocorticoids together with* adrenaline can be reduced by unilateral adrenalectomy However, they prefer the bilateral procedure LERICHE s opinion is that in severe and acute arteritis when other therapeutic measures have been tried and the threat of amputation still exists bilateral adrenalectomy is indicated

In the present series only unilateral operations have been performed because a second adrenalectomy was considered too late in the patients who had to undergo amputation and in the other cases amputation became unnecessary without further measures Substitution therapy after bilateral adrenalectomy would be more complicated and continuous in unilateral cases it is easy and is only required for about a week

It is a well known fact that elderly patients with arteriosclerosis find it difficult if not impossible to learn to use a prosthesis after amputation The loss of one or two toes is of course much less significant and it is the author's considered opinion that more extensive amputation was avoided *in some cases of the present* series Therefore it seems reasonable to continue the policy of offering a patient adrenalectomy — without of course promising

anything — if reconstructive surgery is not suitable sympathectomy has already been done and peripheral arteriosclerotic gangrene is progressing It is worth seriously considering whether adrenalectomy should be performed on such patients at the same time as the sympathectomy

SUMMARY

Umlateral adrenalectomy has been performed on ten patients over the age of 50 with peripheral arteriosclerotic gangrene In six cases sympathectomy had been done previously, in four it was done simultaneously Preoperative angiograms showed that arterioplasty or thromboendarterectomy were not possible Two patients had thigh amputations and one a below knee amputation 1—3 weeks after adrenalectomy The other seven improved and are able to work because major amputation was avoided Three had amputation of a toe or metatarsal bone The follow-up time has been 1/2—3 1/2 years It is the author s opinion, that uni lateral adrenalectomy is worth trying when an arteriosclerotic patient has impending gangrene due to poor skin circulation and all other conventional therapeutic measures except amputation have already been used

RESUMF

La surrenalectomie unilaterale a ete pratiquee pour la gangrène arteriosclerotique des membres inferieurs chez 10 malades, ages de plus de 50 ans Dans 6 cas la sympathectomie avait éte realisee auparavant dans 4 cas celle ci a ete faite simultanement L'arteroplastie ou la thrombo endarterectomie n etaient pas justifiees par les cliches angiographiques preoperatoires 2 malades ont subi l am putation femorale et 1 malade l amputation sous patellaire au cours de 1—3 semaines apres l intervention L etat de sept malades s est ameliore et ils sont capables de travailler parce que les amputations

majeures ont été évitées Dans trois cas on a pratiqué plus tard l amputation digitale ou métatarsale Les malades sont suivis cliniquement de six mois a 3 ans L'auteur conclut que la surrenalectomie unilatérale est justifiée chez les malades souffrant d une gangrène imminente, devenue rebelle aux traitements conventionnels excepté l amputation

ZUSAMMENFASSUNG

Eine unilaterale Nebennierenexstirpation wurde bei zehn uber 50-jahrigen Patienten an peripheren arteriosklerotischen Gangran leidendem durchgefuhrt Bei sechs von denen war schon vorher eine Sympathektomie gemacht worden bei vier wurde sie gleichzeitig durchgefuhrt Die preoperativen Arteriographien haben erwiesen dass die Lage der Arterien keine Arterientransplantation oder Thrombendarteriektomie erlaubte Bei zwei Patienten war man gezwungen eine Oberschenkel und bei einem eine Unterschenkelamputation in 1 bis 3 Wochen nach der Nebennieren exstirpation vorzunehmen Die weiteren sieben sind nach einer Observationszeit von 1/2 bis 3 1/2 Jahren arbeitsfahig wennauch man gezwungen war bei 2 von denen die Amputation einer Zehe und bei einem des funften Metatarsuskopfchens in 1 bis 12 Monaten nach der Nebennierenexstirpation vorzunehmen Nach der Meinung der Verfasser dass in ahnlichen Fallen besonders wenn bei der Hautzirkulation eine Arteriosklerotische periphere Gangraene drohend ist ist es der Muhe wert eine unilaterale Nebennieren exstirpation zu versuchen wenn alle andere Behandlungsmethoden versagen

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ACTA ORTHOPAEDICA SCANDINAVICA

SUPPLEMENTUM No 62

FROM THE CLINIC FOR ORTHOPAEDICS AND TRAUMATOLOGY
UNIVERSITY OF HELSINKI (HEAD: PROFESSOR K. E. KALLIO)

THE EFFECT OF GROWTH HORMONE AND THYROTROPIN ON HUMAN FRACTURE HEALING

A CLINICAL QUANTITATIVE RADIOGRAPHIC AND METABOLIC STUDY

BY

ERKKI V S KOSKINEN

MUNKSGAARD
COPENHAGEN 1963

I t d n F l d
H l k 1963
MERCATORIN KIRJAPAINO

To my Wife

CONTENTS

I INTRODUCTION

Bone repair and the factors affecting its course constitute one of the most prominent considerations in fracture treatment The continuous increase of bone fractures and of traumatic injuries on the whole has given rise to problems which are being approached from new points of view More clearly than before the bone is understood to be a living tissue with its peculiar modes of reaction and with its individual metabolism Not only several investigations concerning the healing of fractures but also the research work pursued on the subjects of osteoporosis bone transplantation and antigen factors to mention only a few has contributed toward the crystallization of these ideas

Well aware of the fundamental prerequisites which are necessary and essential for instituting an adequate orthopaedic therapy and to achieve successful repair of the fracture it has been shown particularly in recent experimental and clinical studies that hormonal factors possess significance in respect of the course of the reparative process in the bone and that it is possible to control it under the effect of certain hormones Striking hormonal influences are well known from the spontaneous fractures which have become common and problematic with the general use of prolonged corticoid therapy The profound effect of the corticoid hormone on the entire organism on the connective tissue and the bone is undisputed and its delaying influence on fracture healing has been convincingly established in several investigations (e g *Albright et al* 1941 *Albright* 1947 *Irvin et al* 1954 *Reifenstein* 1956 1957)

On the other hand the literature reveals that the opinions concerning the influence of different so called anabolic hormones on bone repair are variable the reported results are found to be controversial in many cases when subjected to critical assessment In part this may be due especially

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A preliminary report of the work described in this paper was presented by the author as invited speaker at the Gordon Research Conference on the Chemistry Physiology and Structure of Bones and Teeth in Meriden N H U S A July 9—13 1962

as regards growth hormone to the fact that only in a few recent years so-called pure hormone preparations have been available while the products employed previously used to contain other fractions which could actually exert an influence opposite to that intended with the hormone administration This was true for instance with the hormones of the anterior pituitary such preparations containing growth hormone and also ACTH which are antagonistic in their effects in numerous respects

Since *Evans* and *Long* (1921) succeeded in demonstrating that lack of the anterior pituitary growth hormone isolated by them stimulated the growth of mammal animals which fact was later attributed to the effect of the hormone on the epiphyses of the long bones attention has become essentially concentrated on the bone growth stimulating effect of this hormone and on its use in cases where such an effect is desired

This substance growth hormone or STH stimulates the protein synthesis and retards the decomposition of protein According to *Li et al* (1945) among its most essential physiological effects there are mentioned increase of the serum s alkaline phosphatase activity and of its inorganic phosphorus content and increase of the nucleic acid content in liver and thymus Nitrogen is stored and the excretion of phosphorus sodium and potassium in the urine is reduced It has frequently been observed that the urinary calcium excretion is paradoxically increased *Henneman et al* (1960) explain this peculiarity by pointing out that growth hormone promotes the absorption of calcium and if the incremental calcium cannot rapidly by deposited in new bone substance it appears in the urine Growth hormone is thus seen to be a metabolic hormone presenting remarkable anabolic activity

Thyrotropic hormone affects the thyroid gland and produces its own well known metabolic effects As regards the skeletal system in particular it has been found to possess an *effect promoting the maturation of* bone This term relates to the times of appearance of epiphyseal centres of ossification and the times of cessation of epiphyseal bone growth which is marked by the disappearance of the epiphyseal plates (*Sissons* 1956)

In recent years some valuable papers have been published concerning the significance of growth hormone in respect of the growth of bone and its maturation on the whole which places them in close connection with the present subject Without commenting on them in detail the investigation carried out by *Asling* and *Evans* (1956) may be mentioned which revealed that the bone growth of experimental animals after having been stopped by hypophysectomy could be restored to normal or even stimulated to excess

by administration of growth hormone together with thyrotropin No other hormone had this capacity The effect was markedly augmented through the synergetic action of the thyrotropic hormone

The effect of hormonal factors on fracture repair has been investigated e g by *Shepanek* (1953) who found that growth hormone expands the epi physeal line and promotes greater growth *Blunt et al* (1950) and *Sissons* and *Hadfield* (1952) noted that cortisone had a delaying effect on the repair of fractures According to *Fontaine et al* (1954) thyroxine accelerated the osteogenesis in experimental fractures which was on the other hand de- pressed by desoxycorticosterone and corticotrophine *Moffat* and *Francis* (1955) observed that sex hormones possess significance in the bony repair of fractures Recently *Williamson* (1960) reported that the profit derived from the use of gonadal hormones cannot be assessed before statistically significant results have been obtained with the aid of a control series

In clinical practice favourable results have been obtained with growth hormone in stunted growth caused by endocrine disorders (e g *Henneman et al* 1960) which has been one of the most important indications for the use of human growth hormones *Hernberg* (1960) has reported diabetogenic effects produced with human growth hormone *Prudden et al* (1956) observed that the use of growth hormone had remarkable significance in the treat- ment of burns The evaluation of nitrogen potassium and calcium was enhanced when hormone was given in sufficiently high dosage Clinical applications in the treatment of fractures have been reported e g by *Laborit* (1953) who was able to record positive results of growth hormone therapy in cases with deficient callus formation and in surgical infections *Cordebar* and *Guilleman* (1956) have achieved more rapid osseous consolidation with growth hormone than without it in fracture of various types with con servatively and operatively treated patients Quite recently *Galio* and *Peria* (1958) reported that local application of growth hormone aided the healing of comminuted fractures

Previous investigations concerning the effect of growth hormone on fracture repair in human patients are scanty and based on quite small series without appropriate control series which are indispensable if it is required to obtain an accurate idea of the effect if any and of its character Since the question is one of investigating endocrine actions also metabolic aspects play an important part and the investigation should not be based merely on results recorded on the clinical level which can only furnish a partial answer There is *even greater reason for such an investigation as now a* growth hormone preparation is available which has already in previous

investigations proved effective in man (*Frandsen* 1955 *Carstensen et al* 1954 *Nordstrom et al* 1955 *Paulsen* 1961) in contrast to the variable results obtained with the preparations containing impurities that were used before

In an earlier experimental investigation concerning the repair of fractures a favourable effect of growth hormone and of growth hormone plus thyrotropin on the fracture repair process was noted (*Koskinen* 1959 1962) Among other things the present writer observed that with combined growth hormone and TSH treatment there were similar but even stronger changes indicative of osteogenetic stimulation as in the growth hormone experiments This was evident from the very earliest stages of reconstruction onward as a stronger trabecular formation of new bone the quantity of which increased continuously at a high rate throughout the period of observation Clinical stabilization and roentgenological consolidation of the fracture took place more than twice as rapidly as in the controls The results of autoradiography were consistent with the abundant and early formation of new bone established by the histological line sampling method of *Uotila* (1940 1952)

The present work is an investigation on the effects of growth hormone and thyrotropin on the healing of clinical bone injuries in augmentation of proper conservative or operative therapy as compared with a control series In this investigation attention has mainly been paid to clinical and roentgenological consolidation of the fracture in addition to which a combined radiologic and quantitative planimetric study of the callus formation was carried out the latter reflecting the actual quantity of callus during the progress of bone repair all observations being compared with a control series as reference Simultaneuslv the calcium and phosphorus contents of the serum were determined and the quantity of calcium and phosphorus excreted with the urine was followed as well as the alkaline phosphatase activity of the serum These quantities reflecting the metabolic effect during the repair of bone were also related to an appropriate control series

II MATERIAL

The material on which this investigation is based comprises 60 patie... from the Clinic for Orthopaedics and Traumatology Central Univers... Hospital of Helsinki (Chief Prof K E Kallio M D) All examinations and treatment of these patients took place in the Clinic during the period 19.. — 1962 which was sufficient in length for adequate observation of each cas and for follow up examinations Particulars of the cases have been com... in Table 1 A This hormonal treatment series consists of altogether 61 ca... of which 10 cases were recent fractures of an extremity 21 were ca... non union or delayed union and three cases of malunion 29 of th... fractures were of closed type most of them comminuted while in ... there was a compound fracture Four patients were bilaterall... A considerable part of the injuries were serious ones as can ... also from the relatively high number of compound fractures ... 30 patients treated in the same Clinic for injuries of the sam... hormonal treatment) served as controls (Table 1 B)

For the study involving quantitative determination ... by planimetry of radiograms 20 cases of the hormonal tr... 20 of the controls were employed All these patients had ... femur Ten cases of each series were treated conservativel... intramedullary nailing

An analytic study of metabolic values was carried ... 50 patients from the hormonal treatment series and 1... distribution by types of injury from the controls

The age of the patients in the hormonal treatme... 16 and 78 years mean age 46 years and in the contr... 76 years mean age 41 years

TABLE I MATERIAL WITH CLINICAL RESULTS ESTABLISHED BY RADIOGRAPHY

Assessments of radiographic appearance — Poor callus + Slight callus ++ Fair callus +++ Solid firm callus

A Hormonal Treatment Series

Case No Age Sex	Type and Site of Injury	Surgical Treatment	Hormonal Treatment		Radiographic Appearance after months			Comments and Clinical Result
			Duration days	Started days after trauma or operation	2	4	6	
	Fractures of Femur							
1 62 M	Transverse Middle 3rd	Conservative	37	41	+	++	+++	Solid osseous union in 5 months
2 43 M	Oblique Upper 3rd	Conservative	56	[illegible]	+	+++	+++	Osseous union in 4 months
3 66 M	Oblique Lower 3rd	Conservative	44	12	++	+++	+++	Osseous union in 3 months
4 65 F	Oblique Lower 3rd Bilateral	Conservative	49	11	—	+++	+++	Osteogenesis imperfecta Osseous union in 3 months
5 41 M	Transverse Lower 3rd Compound	Conservative	30	42	++	+++	+++	Consolidation in 3 months
6 [illegible] F	Transverse Middle 3rd	Conservative	64	11	++	+++	+++	Consolidation in 4 months
7 70 F	Oblique Upper 3rd	Conservative	64	13	++	++	+++	Diabetes — Obvious partial soft part interposition but consolidation in 6 months
8 36 M	Transverse Lower 3rd Compound	Conservative	51	14	++	+++	+++	Consolidation in 4 months Soft callus initially but osseous union after 4 months
9 57 M	Oblique Lower 3rd Compound	Conservative	18	16	+	+++	+++	Consolidation in 4 months Callus remained about equal in size as at 2 months but gained in firmness
10 58 M	Transverse Lower 3rd Compound Bilateral	Conservative	41	43	++	+++	+++	Fracture of right femur consolidated in 4 months Fracture of left femur united in 5 months
11 [illegible] M	Transverse Middle 3rd	Nailing	[illegible]	32	++	+++	+++	Consolidation in 3 months
12 18 M	Transverse Middle 3rd Compound and tibial fracture	Nailing	41	19	+++	+++	+++	Osseous union in 2 months Extensive callus developed during 4 months and subsequently decreased Tibial fracture consolidated in 5 months
13 [illegible] M	Oblique Boundary of M and L 3rds	Nailing	16	14	+	+++	+++	Solid union in 4 months Callus increased only slightly in size but gained firm solidity

14 20 M	Transverse Middle 3rd	Nailing	29	0	+ + + + + + + +	Osseous consolidation in 3 months
15 40 M	Transverse Middle 3rd Comminuted Supracondylar fr. of humerus	Nailing	17	14	+ + + + + + + +	Rapid osseous callus formation in 2 months [illegible] in 4 months [illegible] Supracondylar fracture [illegible] in 6 weeks
16 60 M	Transverse Middle 3rd	Nailing	24	20	+ + + + + + +	Consolidation in 4 months
17 1 M	Transverse Middle 3rd	Nailing	1	60	+ + + + + +	Osseous union in [illegible] months
18 18 M	Transverse Middle 3rd and tibial fracture	Nailing	23	13	+ + + + + + + +	Firm callus formation [illegible] in 3 months [illegible] fracture consolidated in [illegible] months
19 19 M	Transverse Middle 3rd	Nailing	26	30	+ + + + + + + +	Osseous union in 4 months
20 20 M	Transverse Middle 3rd Compound	Nailing	39	21	+ + + + + + + +	Osseous union in 3 months

Non union or Delayed Union of Femur

21 [illegible] M	Middle 3rd	Nailing and Tibial Bone Grafting	0	6	+ + + + + + + +	Two previous operations 2 and 3 years ago [illegible] Solid union in 3 months
22 63 M	Middle 3rd	Nailing and Tibial Bone Grafting	68	61	+ + + + + +	Previous skin transplantation [illegible] Solid union after 6 months
23 37 M	Lower 3rd	Trepanation and Sequestrectomy	62	70	+ + + +	Previous [illegible] Solid [illegible] union after 8 months
24 48 M	Upper 3rd	Nailing and Tibial Bone Grafting	–	30	+ + + + + + + +	Previously [illegible] fracture of the hip [illegible] months later [illegible] fracture. Solid [illegible] union of both fractures in 4 months
25 57 M	Upper 3rd	Screws and Tibial Bone Grafting	0	10	+ + + + + + +	[illegible] single fracture [illegible] extensive callus formation [illegible] solid union in [illegible] months
26 19 M	Upper 3rd	Nailing and Tibial Bone Grafting	26	10	+ + + + + +	Previously oblique fracture in upper 3rd treated with [illegible] and refracture. Solid osseous union in 4 months
27 9 M	Middle 3rd	Tibial Bone Grafting	11	123	— + +	Delayed union after [illegible] grafting [illegible] After 6 months [illegible]
28 6 M	Middle 3rd	Trepanation and Tibial Bone Grafting	60	4	+ + +	Previously internal fixation with plate and screws [illegible] refracture [illegible] Consolidation of the fracture [illegible] but after [illegible] months after operation

Table 1 continued

Case No Age Sex	Type and Site of Injury	Surgical Treatment	Hormonal Treatment: Duration days	Hormonal Treatment: Started days after trauma or operation	Radiographic Appearance after months: 2	4	6	Comments and Clinical Result
7 32 M	Fracture of Femoral Neck and Head Comminuted	Arthrodesis	3	40	+	++	+++	Osseous union in 5 months
8 11 M	Posttraumatic Arthrosis of Knee Joint	Arthrodesis	27	6	++	+++	+++	Osseous union in 2 months
9 61 M	Posttraumatic Arthrosis of Knee Joint	Arthrodesis	29	5	++	+++	+++	Osseous union in 2 months
10 11 M	Posttraumatic Arthrosis of Knee Joint	Arthrodesis	20	1	++	+++	+++	Osseous union in 2 months

B Controls

Case No Age Sex	Type and Site of Injury	Surgical Treatment	No Hormonal Treatment	Radiographic Appearance after months: 2	6	4	Comments and Clinical Result
	Fractures of Femur						
1 11 M	Transverse Middle 3rd	Conservative		+	+	++	Osseous union in months
2 63 F	Transverse Lower 3rd Comminuted	Conservative		—	—	+	No osseous union within 10 months
3 60 F	Oblique Lower 3rd	Conservative		—	+	++	Union in 7 months
4 11 M	Transverse Lower 3rd Compound	Conservative		—	+	++	Osseous union in 6 months
5 76 F	Oblique Lower 3rd	Conservative		—	+	+	No osseous union within 8 months
6 63 F	Oblique Lower 3rd	Conservative		++	++	+++	Osseous union in months
7 [illegible] F	Oblique Lower 3rd	Conservative		++	++	++	Solid osseous consolidation in months
8 67 F	Oblique Middle 3rd Comminuted	Conservative		+	++	+++	Osseous union in months
9 17 M	Transverse Middle 3rd	Conservative		—	++	++	Polytraumatic case Osseous consolidation within 8 months
10 31 M	Transverse Boundary of L and M 3rds	Conservative		+	++	++	Osseous union in months
11 11 F	Transverse Upper 3rd	Nailing		—	+	+	Polytraumatic case No osseous union in 8 months

1_ 0 I	I in ve Mi I ll 3r I	Nailing	+ + +	O u unl n in 8 m nth
13 18 M	Tr n r t Upper 3rd Comminute l	Nailing	+ + + + + + + +	S lll c u union in 4 m nth
11 0 I	T ver e Mid ll 3r l Comminuted	Nailing	+ + + + + + + +	Solid union in 4 m nths
1 3 I	Tran v r Lower 3rd Comminuted	Nailing	+ + + + +	O cou u I n in 6 month
16 19 I	T v r Middle 3r l	Nailing	+ + + + + + +	O cus union in 4 m nths
1 19 M	Tr n ver e Mi l ll 3r l	Nailing	+ + + + + +	O eous unl n in m nths
18 44 I	Tr n r Mi l ll 3r l	Nailing	+ + + + + +	O u unl n in 6 m nth
19 1 M	Tr n ver Mi l lle 3rd	Nailing	+ + + + + +	O e us unl n in m nth
20 1 M	Ol li Mid ll 3r l Comminuted	Nailing	+ + + + +	O us unl n in m nth

Fractures of Tibial Shaft

–1 3– I	Tr n r Upper 3rd	C n er tl	+ + + +	O o union in 4 m nth
–2 60 I	Oblique Low 3r l	C n rv tiv	+ + + + +	O eo unl n in month
23 C M	Oblique Lo er 3r l	Conservati e	— + +	O unl n in n nths
–4 49 I	Oblique Lo er 3r l	Conservativ	+ + + + +	Con lid ti n in 6 m nth
2 33 M	I r 3r l Compound Comminut l	Con rvativ	– + +	N o e n e n lid ti n
–6 21 N	Tr ver Middle 3r l	Conservative	+ + + + +	O u unl n in 6 month
–7 16 M	Middle 3r l	Ili B ne Grafting	+ + + + +	Delayed uni n aft r ... fr ... Con lid ti n fter ... gr ft ... ti n in 6 month

Fractures of Cancellous Bone

–8 63 I	Fra ture f Femoral N k	Nailing	+ + + +	O union in m nth
–9 48 M	Pertrochant Fracture f F r	Conservativ	+ + + + +	O e union in 4 m nth
30 61 I	I rtrochant Fracture of Femur	Nailing	+ + + + +	O eous unl n in m nth

2 — Ko k nen

III METHODS

Hormonal Treatment

The treatment of all 60 patients concerned in this investigation included in addition to appropriate orthopaedic care intramuscular administration of 10 U S P units growth hormone (Somatotropine STH)[1] and 2 U S P units thyrotropine (Thyroid Stimulating Hormone TSH) every second day The STH was a chromatographically purified preparation derived from the pig s hypophysis and its above mentioned dosis had an effect equivalent to 25 mg of *Li* and *Wilhelms* preparation

The usual period of hormone administration was 3—10 weeks In cases with non union or delayed union and compound fracture or osseous defect this treatment was longer

Assessment of Osseous Union

For evaluation of the progress of osseous union the development of callus was closely observed during the period of investigation in addition to the clinical examinations Roentgenograms were taken of all patients at regular intervals more frequently during the initial phases of repair in order to check on the position of the fragments At a later stage roentgenological examination took place approximately every second month this was continued until the final result of the repair process was definitely seen The roentgenologic criterion of bony consolidation was a bridgelike callus *formation between the ends of the fragments the fracture line could then* still be visible but without signs of sclerosis If no callus formation was observable no finding of osseous union was recorded the assessment was in such cases deferred to the next examination until consolidation was positively established by the said criteria

[1] Somacton Ferring Malmo Sweden
[2] Actyron Ferring Malmo Sweden

Quantitative Callus Evaluation

In 20 cases of the investigation series proper where fracture of the femur was involved and in an equal number of similar cases belonging to the control series roentgenograms were taken two months and four months after the trauma or surgical intervention and examined for the quantity of callus by the following procedure

From each roentgenogram the outline of the callus was copied on tracing paper and the total area of the resulting figure was determined with the planimeter The mathematical treatment of the values thus found will be described in connection with the results

Laboratory Examinations

The calcium and inorganic phosphorus contents of the patients blood serum and the alkaline phosphatase activity were determined at intervals of one week and in a later phase of the hormonal treatment at intervals of two weeks Similarly the urinary calcium and phosphorus excretion were determined from the collected 24 hour urine The calcium determinations were made by the EDTA titration method and the phosphorus determinations by Dryer s method The alkaline phosphatase activity was evaluated in Bodansky units — The patients were on a constant diet and no milk cheese or fish was given during period of three days prior to each sampling[1]

[1] The dietetic and laboratory work was carried out under supervision of the Physician of the Clinic s Laboratory Department University Lecturer R Cordin M D

IV RESULTS

Clinical Aspects

Hormonal Treatment Series

Of all 64 fractures delayed unions non unions and malunions in the investigation eries proper 62 showed ultimate osseous union In two instances no union was obtained The results proved by radiography and the time when osseous consolidation was established are seen in Table 2 p 38

Table 1 shows in each individual case the age and sex of the patient the type and site of the bone injury the surgical treatment and the period during which hormonal treatment was applied This treatment was continuous during the number of days given in the table Moreover the table gives the time interval that had passed since the trauma or surgical intervention before hormonal treatment was instituted and reports on the radiographic appearance of the callus after 2 4 and 6 months and the ultimate clinical result

The hormone administration was well tolerated by all patients and in many of them improvement of physical condition could be noted during the hormonal treatment No allergic reactions or harmful effects occurred except for slight hyperglycaemia in some cases

Fractures of the Femoral Shaft

The investigation series proper contains altogether 22 fractures of the femur in twenty patients Two of the fractures were located in the upper third of the femur eleven in the middle third and nine in the lower third or on the boundary between middle and lower thirds In the case of twelve fractures the fragments could be brought into alignment and made to retain

their position satisfactorily by conservative therapy consisting of traction and reduction while in ten instances medullary nailing was undertaken in connection with which the point of the fracture was exposed Medullary nailing was considered best and it was the method of choice unless contra-indication was present in the form of fractures in the upper or middle third of the femur In the cases where a supracondylar or oblique fracture was concerned conservative treatment was frequently applied

The duration of combined STH and TSH hormonal treatment was except for three cases with a shorter period of treatment between 21 and 61 days average time of treatment 37 days The time interval from trauma or surgical intervention to commencement of hormonal therapy in the cases with femur fractures was between 12 and 67 days

In all cases osseous union was achieved proved radiologically and by clinical assessment The time required to reach this was 2 months in two cases 3 months in nine 4 months in seven 5 months in three and 6 months in one case

The series includes one patient with osteogenesis imperfecta (Case No 1) whose injury was bilateral low fracture of the femur Combined STH and TSH administration was not commenced until 41 days after the trauma Prior to this time the callus had developed very poorly in the initial stage Roentgenograms taken after six weeks and after eight weeks show no evi dence of consolidation After three months when the patient had received 25 mg STH every second day during four weeks and 28 U S P units thyrotropin a distinct periostal callus had formed bridging the gap between the fragments Bony consolidation of the fractures took place so that the patient could resume weight bearing

The observation emerges from the clinically recorded results that in conservative and operative treatment of femur fractures under STH and TSH therapy callus formation took place within 2—6 months on an average within 3 5 months resulting rapidly in osseous consolidation The results also suggest that the effect on the callus formation was slighter with hormonal therapy of less than 3 weeks duration (Cases No 9 13 17) than when this therapy was continued more than 30 days In all but two cases the hormonal treatment was started at an early phase during the first or second month when the callus formation was under development Hormonal treatment given during this time seems to be optimal as regards callus formation and osseous consolidation

The following case report presents an example of a case involving comminuted fracture of the femur with multiple trauma The fracture was

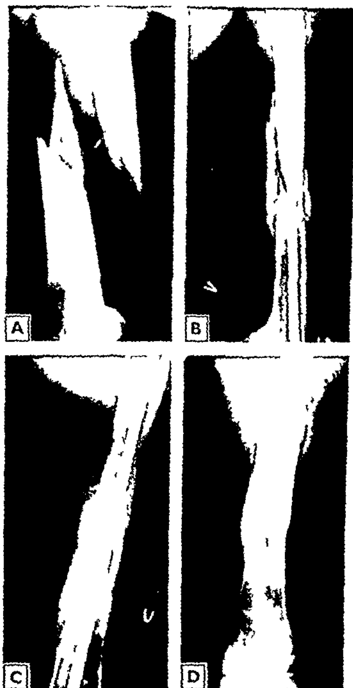
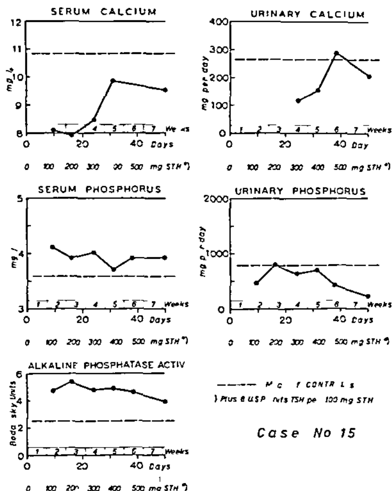


Fig. 1. *Case No. 15.* Roentgenograms of a case with comminuted fracture of the femur (*A*) treated by medullary nailing. Combined growth hormone and thyrotropin treatment applied during 47 days. Rapid osseous callus formation ensued in 2 months (*B*); solid union completed after 3 months (*C*). The nail was removed after 6 months (*D*). — Cf. Fig. 2



Fi_g 2 *Case No 15* — Graphs showing the metabolic response to hormonal treatment of the case concerned in Fig 1 Zero time corresponds to start of hormonal treatment (14 days after operation) — Low calcium content of serum values of 8 1 7 9 and 8 45 mg being recorded during the first four weeks and subsequent increase Corresponding decrease of urinary calcium excretion with values varying between 115 and 285 mg per day — Elevated values of serum phosphorus content as well as alkaline phosphatase activity values as high as 5 3 Bodansky units being recorded for the latter Reduced urinary phosphorus excretion lowest value 210 mg per day indicating retention of phosphorus

treated by medullary nailing and combined STH and TSH therapy was applied with the result of rapid osseous consolidation within two months in the form of a solid osseous formation between the fragments (Figs 1 and 2)

Case No 15 — A mechanic aged 40 sustained in an automobile accident comminuted fracture of the femur fracture of the skull with cerebral injury and supracondylar fracture of the humerus Open retrograde medullary nailing was performed on the eighth day combined STH and TSH therapy was applied during 47 days beginning two weeks after the operation Rapid osseous consolidation ensued between the ends of the fragments and the fracture gained firm stability in two months The supracondylar fracture was repositioned and encased in plaster in anatomical position this fracture was consolidated in six weeks

The calcium content in the patient s blood serum was low the values of 8 1 7 9 and 8 45 mg % were recorded during the first four weeks This was followed by an increase to 9 83 with the final value of 9 5 mg % — The urinary calcium excretion showed a corresponding decrease with values varying between 115 and 285 mg per day — The serum phosphorus content presented increased value as did the alkaline phosphatase activity the highest value recorded for the latter being as high as 5 3 Bodansky units — The urinary phosphorus excretion was reduced indicating retention of phosphorus with a lowest value of 216 mg per day

Non-Union or Delayed Union of Femur

There were eleven cases in which non union or delayed union of the femur had to be treated In all cases an operation was performed most frequently medullary nailing and transplantation of bone In two cases (No 23 and 28) the non union was complicated by osteitis of the femur with a cutaneous fistula as a consequence of an earlier operation

The duration of hormonal treatment in this group varied between 21 and 76 days The average treatment period was 52 days which is the highest among all different groups constituting the material of this investigation Hormonal treatment was commenced at times between 3 and 70 days after the operation except for one case (No 27) in which STH and TSH treatment was given exceptionally as late as four months after the operation during a period of 41 days In this case another bone graft operation was considered because no consolidation had taken place The patient requested a postponement and was left under observation Examination after two months revealed that the fracture had consolidated without further operative treatment

All eleven cases in this group presented serious injuries which had already been treated previously but which had not responded to treatment or were complicated by refracture or osteitis In ten of them osseous union proved by radiography was achieved corresponding to 90 % successful recovery The time required for consolidation to occur was 3 months in two cases 4 months in three 5 months in two 6 months in two and 8 months

in one case average 13 months In one case with non union and osteitis (Case No 28) the infection abated and incipient consolidation could be observed but the patient succumbed to a heart attack five months after trepanation and bone graft operation

It can be noted that in the cases in which the hormonal treatment was started within 30 days after the operation and continued during a long period up to 52—76 days (Cases No 21 24 25 29) osseous consolidation took place sooner In the cases in which hormonal treatment was instituted at a later stage more than 40 days after the operation (Cases No 22 23 27 31) and had a duration of 59—68 days consolidation was obtained but it took a correspondingly longer time In the case with accompanying infection (Case No 23) repair of the bone was very slow as compared with the aseptic cases but bony consolidation was ultimately attained

As an example of non union of the femur which did not respond favourably to two previous operations Case No 21 may be cited In this case the effect of hormone administration is reflected by the decrease of the serum calcium content and the steep decline of urinary calcium excretion (Figs 3 and 4)

Case No 21 — An engine stoker aged 22 sustained 23 VIII 1958 in a traffic accident a fracture of the left femur 28 VIII 1958 osteosynthesis (Lane) 3 IV 1959 trepanation and bone graft operation Non union and varus deformity developed disabling the patient 6 XI 1960 osteotomy intramedullary nailing and iliac bone graft operation were performed and combined STH and TSH hormone treatment was applied during eight weeks The bone fragments were sclerotic and avascular and the space between them was filled with abundant fibrous tissue The bone graft applied at the preceding operation which was calcified and had failed to unite was removed Recovery took place without complications after three months (10 II 1961) the gap between fragments and the bone sclerosis had disappeared while at the point of non union a dense but not excessive callus formation was noted The patient was allowed to move freely and to resume weight bearing Complete osseous consolidation of the fracture and normal function ensued — The serum calcium content decreased during the first three weeks from 10 1 to 9 3 mg % Urinary calcium excretion fell abruptly to a low level (from 340 mg per day initially to 24 mg per day) which persisted throughout the period of hormone application The serum phosphorus content displayed an increasing tendency initial value 3 6 and highest value 4 2 mg % There were no marked changes in urinary phosphorus excretion or alkaline phosphatase activity

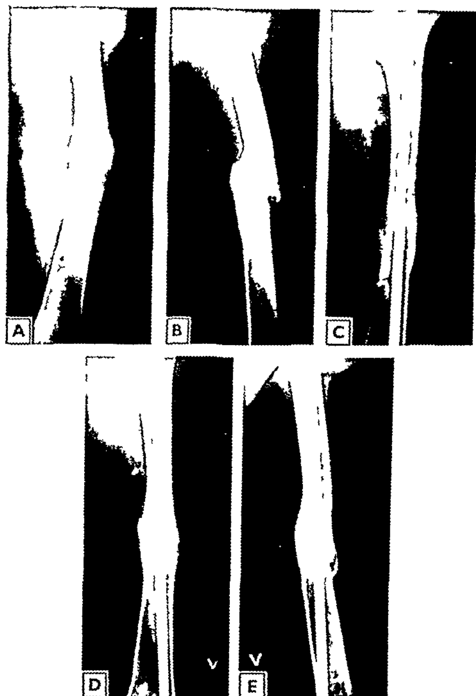


Fig 3 (Case No 1) Roentgenograms illustrating osseous consolidation in a case of non union and varus deformity following fracture of the femur (A B) Combined growth hormone and thyrotropin treatment applied during eight weeks starting [illegible] days after the operation The surgical treatment was osteotomy and intramedullary nailing with bone grafting A firm non excessive callus formation can be seen after 3 months (C) End result after [illegible] months complete osseous union with good anatomical position (D F) (cf Fig 4)

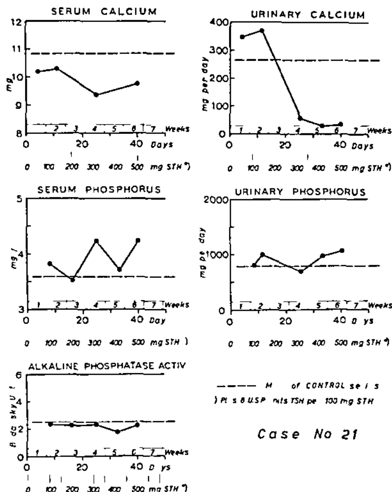


Fig 4 *Case No 21* – Graphs showing the metabolic response to hormonal treatment of the case concerned in Fig 3 Zero time corresponds to start of hormonal treatment (6 days after operation) — Decrease of serum calcium content during the first three weeks from 10 1 to 9 3 mg Abrupt decline of urinary calcium excretion to a low level (from 340 mg per day initially to 24 mg per day) persisting throughout the period of hormone administration — Increasing tendency of serum phosphorus content Initial value 3 6 and highest value 4 2 mg — No marked changes in urinary phosphorus *excretion or alkaline phosphatase activity*

In the next case an example is encountered of the refracture of osteoporotic bone in the subtrochanteric region after nailing of the femoral neck In this case too a distinct decrease in urinary calcium excretion was observed during the time of hormone administration Also the urinary phosphorus excretion was seen to decrease and the serum phosphorus content displayed fairly high values (Figs 5 and 6)

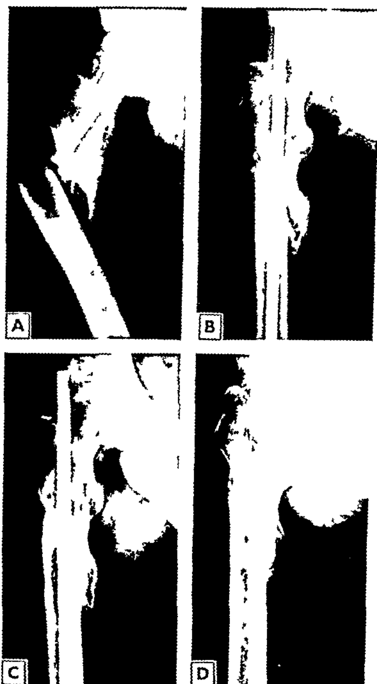


Fig. [illegible] Roentgenograms illustrating osseous consolidation in the case of a [illegible] with subtrochanteric fracture of the femur at the point of insertion of the [illegible] months previously owing to fracture of the femoral neck (*A*) combin[illegible] with [illegible] thyrotropin treatment applied during 52 days. The surgical treatment [illegible] nailing and iliac bone grafting. Some increase of blood sugar valu[illegible] of treatment, but no ketonuria. — Rapid callus formation [illegible] 4 months, *D* [illegible] months after the operation) [illegible] ability was restored [illegible] Fig. [illegible]

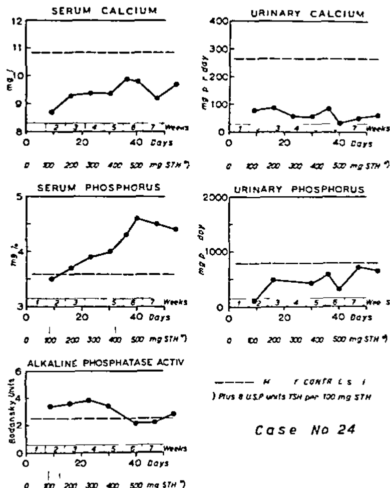


Fig 6 *Case No 4* — Graphs showing the metabolic response to hormonal treatment of the case concerned in Fig 5 Zero time corresponds to start of hormonal treatment — Lowered serum calcium level Urinary calcium excretion fell to 30 mg per day and maintained a low level throughout the period of hormonal treatment — Elevated serum phosphorus content with values up to 4 6 mg urinary phosphorus excretion mostly below 500 mg per day Alkaline phosphatase activity showed increased values up to 3 8 Bodansky units

Case No 4 — A diabetic electrician aged 48 sustained a fracture of the femoral neck which was treated by nailing 25 X 1960 After two months (28 XII 1960) a subtrochanteric fracture occurred in the same leg at the point of entrance of the nail Intramedullary nailing with iliac bone graft was performed and combined STH and TSH treatment was applied during 52 days starting on the 30th postoperative day At the same time 24 units insulin were given daily The blood sugar values somewhat increased during hormonal treatment (218—264 mg% compared to previous 125—215 mg%) but no ketonuria occurred Healing of the fracture

was uneventful and a dense bony callus developed After three months weight bearing could be resumed and good functional ability was regained — The serum calcium level was lowered and urinary calcium excretion decreased to 30 mg per day maintaining a low level throughout the period of hormonal treatment Elevated serum phosphorus content was noted with values between 4 3 and 4 6 mg% while the urinary phosphorus excretion was mostly below 500 mg per day At the same time the alkaline phosphatase activity showed increased values up to 3 8 Bodansky units

Fractures of the Tibial Shaft

Altogether ten fractures of the tibia or fibula were present in eight patients The cases with fractures of tibia and femur both have been referred to the femur fracture group and do not appear here Five patients had a compound fracture and all but one of the others had comminuted fractures All fractures were located in the middle and lower thirds of the lower part of the leg except for one bilateral case with one fracture in the upper and another in the lower third

Except for one case treated by open reduction and screw fixation the treatment was conservative in all cases consisting of closed reduction and plaster cast These patients stayed only a relatively short time in the Clinic and the periods of hormonal treatment were shorter than in the group of femur injuries average duration of hormone administration was 22 days

The results reveal that bony consolidation of the fracture took place in nine out of ten cases equivalent to 90 % successful recovery average con solidation time was 4 0 months Roentgenographic and clinical consolidation was achieved within 3 months in two cases (No 31 and 35) in 4 months in four cases (No 37 and 38 the bilateral fracture case No 33 and the fracture of the right tibia in Case No 36) in 5 months in one case (left lower leg of Case No 36) and in 6 months in one case with compound fracture (Case No 32) In one case osseous consolidation failed to occur namely in Case No 39 involving compound fracture of the lower third of the lower part of the leg in a man aged 66 Subsequent operation with bone graft resulted in consolidation in this case

Non-Union or Delayed Union of Tibia

The material contains four cases of non union or delayed union in the lower part of the leg In two of them (Cases No 10 and 11) osteitis of the fragment ends and cutaneous fistula were present as a consequence of compound fracture when the treatment was commenced The third case (No 12) was one of non union after compound fracture that had occurred five years

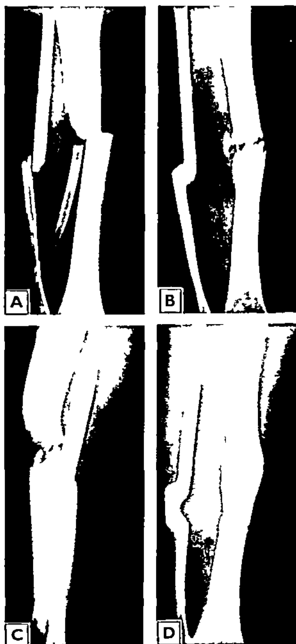


Fig 7 *Case No 40* — Roentgenograms of a case with serious compound fracture of tibia and fibula with bone defect of the tibia (*A*) The case was complicated by osteitis and non union (*B* *C*) Surgical treatment was osteotomy of fibula and compression osteosynthesis of tibia Combined growth hormone and thyrotropin treatment was applied during eight weeks plus antibiotics — The symptoms of inflammation were allayed and solid osseous union was achieved in 8 months (*D*) — Cf Fig 8

Fractures Delayed Union or Non-Union of Cancellous Bone

13 cases in the material concern injuries of cancellous bone Five of them were injuries of the femoral neck namely two recent fractures (Cases No 48 and 49) and three cases of delayed union or non-union (Cases No 53 54 and 55) Three others (Cases No 50 51 and 52) were trochanteric fractures in one case (No 56) there was non union after a pertrochanteric fracture and one case (No 57) concerned comminuted fracture of the neck and head of the femur Finally three patients referred to this series suffered of malunion after intraarticular fracture with secondary arthrosis (Cases No 58 59 and 60)

Conservative methods of therapy were followed in one case with injury of the femoral neck (Case No 48) and in the four recent trochanteric fracture cases (No 50 51 52 and 53) In the other cases operative treatment was applied namely clavifixation (in Cases No 49 and 54) intertrochanteric osteotomy (Cases No 55 and 56) or arthrodesis (Cases No 57 58 59 and 60)

The duration of hormonal treatment in this group of cancellous bone injuries varied between 20 and 62 days on an average 35 days Except for two cases with delayed union subsequent to fracture of femoral neck (Cases No 53 and 54) this treatment was commenced not later than 48 days after the trauma or surgical intervention

In all thirteen cases osseous consolidation was achieved This took place within 2—6 months (average 3 2 months) namely 3 and 4 months respectively in the two cases with recent fracture of the femoral neck (Cases No 49 and 48) within 4 months in one case with non union after fracture of the femoral neck (Case No 55) and in one case with non union after trochanteric fracture (Case No 56) In the cases involving fresh trochanteric fractures consolidation was recorded after 2 months in one case (No 52) and after 3 months in two others (Cases No 50 and 51) After arthrodesis of the hip joint in comminuted fracture of the neck and head of the femur consolidation took place within 5 months (Case No 57) and after arthrodesis of the knee joint firm union could be established after 2 months (Cases No 58 59 and 60) It is worth mentioning that in two cases of injury of the femoral neck with delayed union (Cases No 53 and 54) in which hormonal treatment was instituted more than 100 days had passed since the fracture osseous union was produced

The obvious beneficial effect of hormonal treatment at a late time is illustrated by the report of a case (No 54) involving delayed union after transcervical fracture of the femoral neck (Figs 9 and 10)



Fig 9 *Case No 54* — Roentgenograms illustrating a case of transcervical fracture of the femoral neck (*A* *B*) with delayed union after previous nailing Gap between the fragments and incipient sclerosis observable 3 months after the nailing (*C*) Combined growth hormone and thyrotropin treatment applied during two months The result 3 months after the start of hormonal treatment is seen in Fig *D* which shows osseous union — Cf Fig 10

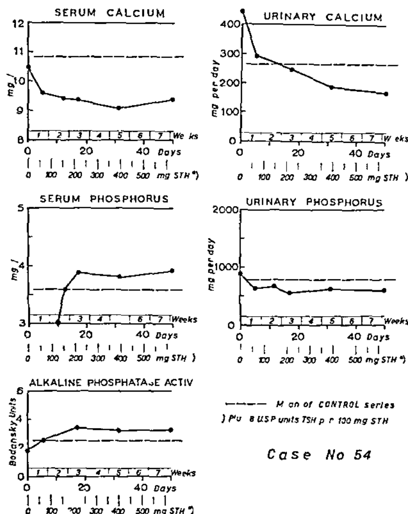


Fig 10 *Case No 54* — Graphs showing the metabolic response to hormonal treatment of the case concerned in Fig 9 Zero time corresponds to start of hormonal treatment — Serum calcium content decreased during the time of hormonal treatment being lowest at about 5 weeks and remaining below the control level also in its subsequent rise Urinary calcium excretion reveals calcium retention which increased in the course of treatment — Serum phosphorus content and alkaline phosphatase activity were slightly elevated from control level

Case No 54 — A widow aged 58 female sustained a transcervical fracture of the neck of the femur which was treated by nailing on the day after the fracture 20 X 1961 Repair of the fracture was delayed after 3 months (26 I 1962) roentgenography revealed a distinct gap between the fragments Combined STH and TSH treatment was commenced which was continued through two months at a dosage of 25 mg STH and 2 U S P units TSH every second day totalling 775 mg and 62 units respectively On 12 III 1962 the gap between the fragments was found to be reduced

and roentgenographic examination on 21 IV 1962 established osseous consolidation — The metabolic characteristics recorded in this case show that the serum calcium content decreased during the hormonal treatment being lowest at about 5 weeks and remaining below the control level also in its subsequent rise The urinary calcium excretion revealed calcium retention which increased in the course of treatment Serum phosphorus content and alkaline phosphatase activity were slightly elevated from the control level

Control Series

Among the cases constituting the controls of the present investigation presented in Tables 1 and 2 there were 20 fractures of the femur in 17 of which osseous consolidation took place within 4—8 months (average 5 3 months) namely within 4 months in three within 5 months in eight within 6 months in four within 7 months in one and within 8 months in one case Three cases presented no roentgenological evidence of union

The number of tibial fractures was six in five of which consolidation occurred within 4—7 months (average 5 5 months) one compound tibial fracture did not progress to consolidation A case of non union of the tibia in which bone graft operation had been performed united in 6 months

Of the three fractures of cancellous bone in this series one fracture of the femoral neck showed osseous consolidation in 7 months and two trochanteric fractures had consolidated within 4 and 5 months respectively

It has to be noted that the control series contains no cases in which osteitis would have been present while in the hormonal treatment series this complication existed initially in four cases It is therefore appropriate in the subsequent comparison of both series to disregard one of the last-mentioned injuries which failed to unite

Comments

Summarizing the main results reported in this chapter the following observations can be stated

Osseous consolidation took place in 62 out of the 64 bone injuries in the material with combined growth hormone and thyrotropine administration in addition to appropriate orthopaedic treatment Excluding one case of non union in which osteitis was present as complication union failed to occur in one case (1 5 %) In the control series of 30 cases osseous union ensued in 26 and failed to take place in four (13 5 %) — Cf Table 2

TABLE 2 CLINICAL RESULTS IN THE HORMONAL TREATMENT SERIES AND CONTROL SERIES PROVED BY RADIOGRAPHY

Type of Injury	Hormonal Treatment Series: Injuries Total	Number of Injuries showing consolidation after months: 2	3	4	5	6	7	8	Failures of Union	Control Series: Injuries Total	Number of Injuries showing consolidation after months: 4	5	6	7	8	Failures of Union	Average Consolidation Time in successfully consolidated cases (months): Horm. Treatm. Series	Control Series	Diff.
Fracture of femur	22	2	9	7	3	1			—	20	3	8	4	1	1	3	3.5	5.3	1.8***
Non union or delayed union of femur	11		2	3	2	2		1[2])	1[2])								4.3		
Fracture of tibia	10		2	5	1	1			1	6	1	1	2	1		1	4.0	5.5	1.5
Non union or delayed union of tibia	4			1	1		1[2])	1[2])	—	1			1			—	4.5	(6)	
Fracture of humerus	2	2							—								2.0		
Non union or delayed union of humerus	2		2						—								3.0		
Fracture of femoral neck	3		1	1	1[3])				—	1				1		—	3.9	(7)	
Non union or delayed union of femoral neck	3			1	1	1			—								4.9		
Trochanteric fracture	3	1	2						—	2	1	1				—	2.6	4.5	1.9
Non union of trochanteric fracture	1			1					—								(4)		
Malunited condylar fracture	3	3							—								2.0		
All injuries	64	8	13	19	9	5	1	2	2	30	5	10	7	3	1	4	3.7	5.3	1.6*
All injuries[1])	63								1	30						4			
	100								1.5 %	100 %						13.5 %			

[1]) 1 ostitis complicated non union of femur omitted
[2]) Non union and ostitis (not included in average consolidation time values)
[3]) Comminuted fracture of femoral head and neck
[4]) Logarithmic mean

Highly significant difference (P < 0.001)

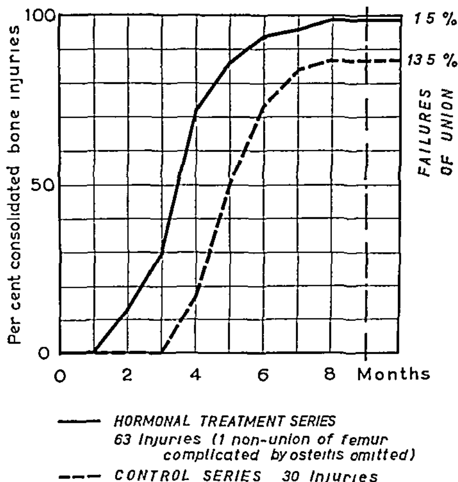


Fig 11 Radiographically established clinical results in the hormonal treatment series and control series Percentages of injuries (fractures delayed unions or non unions) observed to have consolidated within number of months marked on x axis and percentage of ultimate failures of union

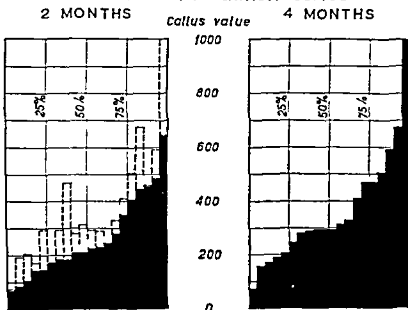
In Fig 11 the average progress of consolidation in the hormonal treatment series is made evident by a line representing the percentage of all cases in the series that have been recorded as consolidated within 2 3 4 months etc The corresponding (dotted) line derived from the results of the control series shows a nearly constant delay of 1 5—2 months *(horizontal distance) in comparison* — The figure also shows the percentage of ultimate failures *i e* of fractures that have not united in 8 months This percentage is nine times as high in the control series (13 5 %) as that in the hormonal treatment series (1 5 %)

TABLE 2 CLINICAL RESULTS IN THE HORMONAL TREATMENT SERIES AND CONTROL SERIES PROVED BY RADIOGRAPHY

Type of Injury	Hormonal Treatment Series									Control Series							Average Consolidation Time in successfully consolidated cases (months)		
	Injuries Total	Number of injuries showing consolidation after months							Failures of Union	Injuries Total	Number of injuries showing consolidation after months					Failures of Union	Horm. Treatm. Series	Control Series	Diff
		2	3	4	5	6	7	8			4	5	6	7	8				
Fracture of femur	22	2	9	7	3	1			—	20	3	8	4	1	1	3	3.5	5.3	1.8***
Non-union or delayed union of femur	11		2	3	2	2		1[1])	1[1])								4.3		
Fracture of tibia	10		2	5	1	1			1	6	1	1	2	1		1	4.0	[illegible]	1.5
Non-union or delayed union of tibia	1			1	1		1[2])	1[2])	—	1			1			—	[illegible]	(6)	
Fracture of humerus	2	2							—								2.0		
Non-union or delayed union of humerus	2		2						—								3.0		
Fracture of femoral neck	3		1	1	1[3])				—	1				1		—	3.9	(7)	—
Non-union or delayed union of femoral neck	3			1	1	1			—								4.9		
Trochanteric fracture	3	1	2						—	2	1	1				—	2.6	[illegible]	[illegible]
Non-union of trochanteric fracture	1			1					—								(4)		
Malunited condylar fracture	1	1							—							—	2.0	—	—
All injuries	61	8	18	13	[illegible]	[illegible]	1	2	2	30	4	10	7	3	1	1	3.7	5.3	[illegible]***
All injuries[4])	63 100								1 1.5%	30 100						1 3.3%			

[1]) 1 osteitis complicated non-union of femur omitted
[2]) Non-union and osteitis (not included in average consolidation time values)
[3]) Comminuted fracture of femoral head and neck
[4]) Logarithmic mean

*** Highly significant difference (P < 0.001)



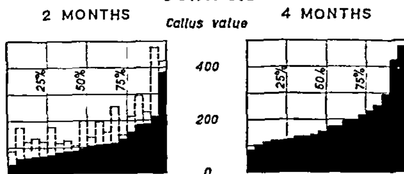


Fig 12 Callus values found by planimetry of roentgenograms in hormonal treatment series and control series (20 femur fractures each) after 2 months and 4 months shown by columns arranged according to their height — *Dotted columns in graphs referring to 2 months* indicate values reached at 4 months in each individual case Unit of callus value = 4 mm² area in roentgenogram

in the hormonal treatment series and 20 controls were evaluated by planimetration as described in Chapter III All 40 patients concerned here had a fracture of the femur ten cases of each series were treated conservatively and ten cases by intramedullary nailing

The readings of the planimeter (in units equivalent to 4 mm of callus x-ray projection area) are called callus values in the following They have been presented in Fig 12 by columns, each column representing by its height the callus value of one patient and the columns have been arranged in the order of their height The four sets of columns separate for the controls and for the hormonal treatment series and for the time of 2 months and 4 months in either case reveal stronger formation of callus in the hormonal treatment group They also show the development of callus that has taken place between the times of 2 and 4 months the callus values of the latter time have furthermore been shown in the two-month diagrams as dotted columns collated to the earlier value of the same individual case

For closer statistical analysis the cumulative frequency curve of the callus values was plotted on normal distribution paper in each instance with logaritmic callus value abscissae (Fig 13) It is seen that the logarithmic values have normal distribution On the strength of this fact the calculation of mean values and the standard deviation considerations were performed on a logarithmic basis The results are presented in Table 3 and Fig 14

The average quantity of callus at 2 months as well as at 4 months was thus about twice as high in the hormonal treatment series as in the control series and the difference is highly significant in both instances The relative

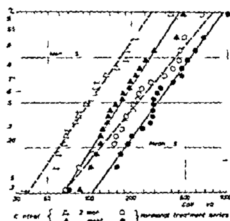


Fig 13

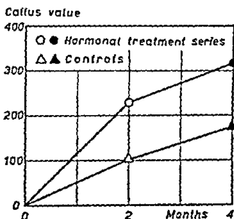


Fig 14

Fig 13 Cumulative frequency distribution plots of callus values found by planimetry of roentgenograms in hormonal treatment series and control series (20 femur fractures each) after 2 months and after 4 months revealing normal distribution of callus value logarithms and consequent appropriateness of treating the values statistically on a logarithmic basis

Fig 14 Average callus values (logarithmic means) in hormonal treatment series and control series (20 femur fractures each) in terms of time since trauma or operation

TABLE 3 FORMATION OF CALLUS IN FEMUR FRACTURES ACCORDING TO PLANIMETRY OF RADIOGRAMS

Time since fracture or surgical intervention	Callus value [1]	
	Control series (20 cases)	Hormonal treatm series ([illegible] cases)
2 months	101	278
4 months	172	316

[1]) Logarithmic means 1 Unit = 4 mm^2 area in x ray

Highly significant difference
Nearly significant difference

excess of the callus size in the hormonal treatment group over that of the controls is less at 4 months than at 2 months this indicates in another way the fact also clearly evident from Fig 14 that the two-month callus average of the controls is only about half of their four month average (highly significant difference) whereas in the hormonal treatment series the average at 2 months is nearly 3/4 of that found for 1 months (only nearly significant difference) The important deduction from this is that the callus of the hormonally treated patients is not only greater in absolute quantity but especially is formed and obtains its maximum size at an earlier time than in the control series

Metabolic Aspects

Of the metabolic characteristics (serum calcium and phosphorus contents urinary calcium and phosphorus excretions and alkaline phosphatase activity) altogether 574 test values determined in the laboratory and derived from 50 patients of the present hormonal treatment series were available A total of 105 corresponding values from the 13 patients of the respective control series served as a reference basis For each of the five above mentioned characteristics the values concerning observations made on the 1st to 50th day of hormone administration have been plotted in Figs 15 and 16 identified by different symbols according to site of injury and surgical aspect Dotted lines in the figures indicate the control level found as a mean of the control observation and the deviation upward and downward of this level by the amount of the standard deviation in the control series has

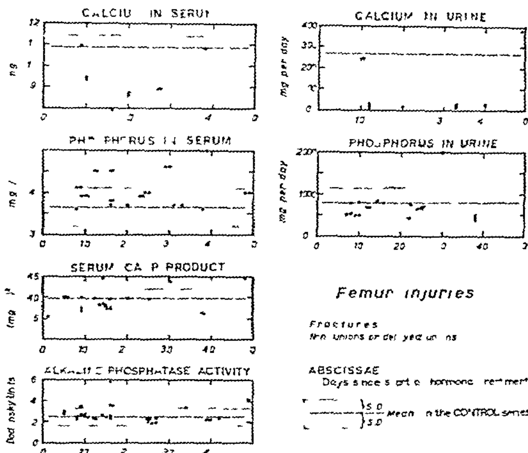


Fig. 15 Plots of metabolic values recorded in hormonal treatment series (fractures delayed unions and non unions of femur) and of serum calcium phosphorus products computed from them up to 50th day since start of hormonal treatment. — Dotted lines indicate mean level recorded in control series and shaded belts indicate spread equivalent to single standard deviation of the control series in either direction of its mean

been shown as a shaded belt in each diagram The plots display a grouping indicating departures in certain directions from the control level of the various metabolic values and this will be substantiated by the following more detailed analysis

Table 4 contains for each of the five characteristics the means of the control observations and of the observations in the hormonal treatment series the latter having been calculated separately for different groups of patients (different sites of injury and different surgical aspects) as well as for the entire series of 50 patients The last column in the table gives the *corresponding* value of the product obtained by multiplying the serum calcium content and the serum phosphorus content The role played by this

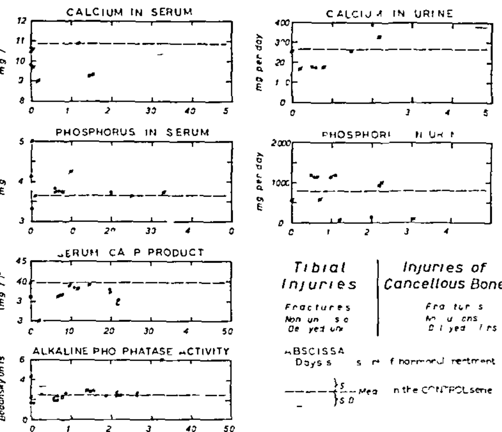


Fig 16 Plots of metabolic values recorded in hormonal treatment series (fractures delayed unions and non unions of tibia and of cancellous bone) and of serum calcium phosphorus products computed from them up to 50th day since start of hormonal treatment — Dotted lines indicate mean level recorded in control series and shaded belts indicate spread equivalent to single standard deviation of the control series in either direction of its mean

quantity in blood chemistry as described in the literature will be discussed later

On the whole the table reveals that in the laboratory tests taken during hormonal treatment the serum calcium was lower than in the controls the serum phosphorus was higher while the urinary calcium and phosphorus excretion were both lower and the alkaline phosphatase activity was higher than the control level The departures in the said directions from the control level which shall be referred to as the hormonal effect in the following constitute statistically highly significant differences[1] in respect of serum

[1] $P < 0.001$ Highly significant difference
$P < 0.01$ Significant difference
$P < 0.05$ Nearly significant difference

calcium content and urinary calcium excretion while there is a nearly significant difference in serum phosphorus level The absence of statistically significant differences in the other two metabolic characteristics (urinary phosphorus and alkaline phosphatase activity) is partly due to the fact that in some of the subgroups of the hormonal treatment series the deviation from control level was opposite in direction to the hormonal effect noted on the whole This shall be discussed in detail below

Site and Type of Bone Injury

Injuries of the femoral shaft — In the group of the hormonal treatment series relating to injuries of the femur the values reflecting the calcium and phosphorus metabolism differ strikingly from the control level The decrease of the serum calcium content from the control level of 10 85 mg% to 9 15 mg % is statistically highly significant as is also that of the urinary calcium excretion from 265 to 140 mg per day The same applies to the increase of serum phosphorus from 3 65 to 4 05 mg % The decrease in urinary phosphorus excretion from the control level of 790 mg per day to 600 mg per day is statistically significant and the increase of alkaline phosphatase activity from 2 5 to 3 1 Bodansky units is nearly significant

Injuries of the tibial shaft — In this group the departure of serum calcium from the control level is only half of what it was in the group of femur injuries but the difference is still statistically significant The hormonal effect noted in the urinary calcium excretion is considerably less than in the femur group and there is no statistically significant difference in respect of this or any of the other three characteristics The mean found for the serum phosphorus content is virtually the same as in the control series and the urinary phosphorus excretion seems to indicate an opposite trend to the generally established hormonal effect

Injuries of cancellous bone — All means in this group display a hormonal effect similar in direction to that in the femur group but the deviations from control level except for the striking decrease of serum calcium are much less and virtually nil for serum phosphorus and urinary calcium There are no statistically significant differences except for that of serum calcium

Comparison of the hormonal effect in the different groups reveals that the effect is strongest in the femur group less in the group of cancellous bone injuries and least of all in the tibial injury group Several of the differences in effect between the groups consistent with this trend are statistically significant as can be seen in Table 1

TABLE 4 MEANS OF METABOLIC VALUES IN HORMONAL TREATMENT SERIES (0 CASES) AND CONTROL SERIES

	Surgical Aspect	Number of Cases	Duration of Hormonal Treatment Mean Days	Serum Calcium Content mg	Serum Phosphorus Content mg %	Urinary Calcium Excretion mg per day	Urinary Phosphorus Excretion mg per day	Alkaline Phosphatase Activity Bodansky Units	Serum Ca P Product (mg)*
ormonal treatment series									
(a)	1)	13	38	9 2*** } 9 8***	1 1*** } 1 1***	200 } 180*	630 } 610	2 8 } 3 3*	37 5 } 37 5
emur	2)	1	31	9 1**	1 2**	110*	40	(1 6)	36 .
njuries	3)	11	19	9 7***	1 0**	100***	30*	2 0	38
	1) 2) 3)	28	11	1 1 **	10 **	110 **	100**	1 1*	37 .
(b)	1)	7	23	10 2* } 10 .	3 3 } 3 9	210 } 210	1000 } 1000	2 2 } 2 2	33 } 39
ibial	2)	—	—	—	—	—	—	—	—
njuries	3)	1	27	10 1*	3 3	(170)	(300)	2 8	15* *
	1) 2) 3)	11	2 .	10 1 .**	3 75	200	100	2 3	37
(c) ancellous	1)	3	10	1 1* } 1 1***	3 . } 3 8	(230) } 300	(600) } 600	. 1 } 2 8	11 * } 11 . *
Bone	2)	3	39	9 . **	1 1	(170)	(800)	1 1	(3 0)
njuries	3)	.	31	9 .***	3 6	210	10	3 .	3 . .*
	1) 2) 3)	11	3 .	9 70***	3 70	210	6 0	3 0	3 . *
ll Cases	1) 2) 3)	30	36	9 . .	3 0 .*	1 . . *	600	. 3 .	38
ontrols									
	1) 2) 3)	13	—	10 8 .	3 . .	20	700	2 0	40
Differences between groups									
(a)—(b)				—0 7**	+0 3**	—60	100	0 6	
(a)—(c)				+0 1 .	+0 3 . *	— 120 *	0	0 1	
(c)—(b)				—0 8 .**	- 0 0 .	+60	110	1 0	

1) Fractures conservatively treated

*** Highly significant difference (P 0 001)

Non Union or Delayed Union

Within each above mentioned group means of the metabolic characteristics have also been computed separately for cases with recent fractures and for those with non-union or delayed union and presented in Table 4 *On the whole hormonal treatment seems to have elicited a stronger response* in the cases with non union or delayed union Particularly the urinary calcium excretion found for the femoral non-unions differs by a statistically highly significant amount from the control level whereas the complementary group of recent femur fractures only displays a nearly significant difference

As far as a comparison is possible between cases which were not affected with non-union or delayed union and which were treated operatively and conservatively the impression is that the hormonal effect seems to have been strong in operated than in conservatively treated cases

Amount of Dosage

The differences in response to hormonal treatment reported in the foregoing may be partially due to the circumstance that the different groups are not mutually fully equivalent with respect to duration of the hormone administration *i e* that in some means metabolic test values referring to samples taken only after a short time of hormonal medication dominate while in others the values referring to a long period of treatment may be *in the majority A detailed study of the effect of hormonal treatment time* that is of the accumulated quantity of hormones given to the patient has therefore been made

For this purpose an analysis was made of the 20 cases in which the duration of hormonal treatment was 30 days or more The distribution of these cases by site and aspect of the injury (*e g* non union) is satisfactorily consistent with that of the entire series and it can be considered a representative miniature sample of the whole material The recorded metabolic values were arranged by the time of hormonal treatment in ten day groups *(1—10 11—20 21—30 31—40 and 41—75 days) and the respective means* together with their standard deviations can be seen in Table 5 which also contains the means of the control series and their standard deviations and a column stating the Ca P product for each group (Fig 17)

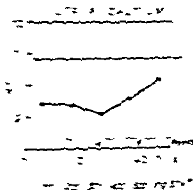
It can be seen that already within the first ten days of hormonal treatment the *serum calcium* decreases abruptly from 10 85 mg % control level to 9 5 mg % The decreasing tendency continues until a minimum of 9 1 mg % is seen about 25 days The subsequent increase carries to the mean

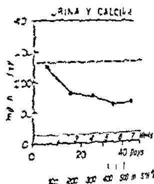
TABLE [illegible] MEANS OF METABOLIC VALUES IN SERIES OF 20 CASES WITH HORMONAL TREATMENT OF NOT LESS THAN 30 DAYS DURATION AND IN THE CONTROL SERIES

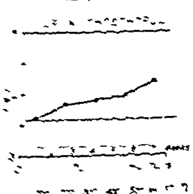
Time Since Start of Hormonal Treatment days	Serum Calcium Content mg		Serum Phosphorus Content mg		Urinary Calcium Excretion mg per day		Urinary Phosphorus Excretion mg per day		Alkaline Phosphatase Activity B Linsky Units		Serum Ca P Product (mg %)²	
	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
1—10 (a)	9.5***	1.0	3.7	0.1	250	140	680	380	3.2	1.1	36	[illegible]
11—20 (b)	9.4	1.0	3.8	0.1	180	130	660	480	3.0	1.0	36*	4
21—30 (c)	9.1***	0.7	3.9	0.1	150	1[illegible]0	660	210	2.9	0.8	3[illegible]*	3.5
31—40 (d)	10.[illegible]*	0.5	4.0	0	125*	110	500	320	3.3	1.3	37.5	6
41—75 (e)	10.2*	1.0	4.2	0.1	1[illegible]5**	100	550	300	2.3	0.[illegible]	42	5.5
Controls	10.85	0.5	4.0	0.1	205	120	700	380	2.0	0.8	41.5	4.5

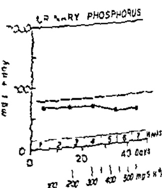
*** Highly significant difference ($P < 0.001$)
** Significant difference ($P < 0.01$)
* Nearly significant difference ($P < 0.05$)
In the table Referred to Controls

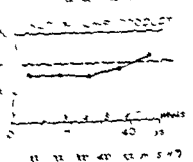
Differences between groups Serum Calcium (e c)**
Serum Phosphorus (a e) (b e) (c e)
Serum Ca P (a e) (d e) (c e)

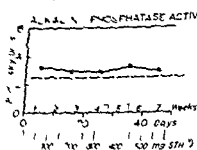












——— Mean of CONTROL series

? P is 8 US? units TSH per 100 mg S H

Fig. 17. Means of metabolic values recorded in hormonal treatment series (20 cases) and prior to hormonal treatment during 30 days or longer) and of the serum calcium [illegible] computed from them for periods of 1–10, 11–20, 21–30, 31–40 and 41–[illegible] start of hormonal treatment — Dotted lines indicate mean level recorded in the control series

of 10 2 mg °₀ during continued treatment in excess of 40 days Distinct response to hormonal treatment would thus be concentrated in the first 3—4 weeks The last mentioned value indicating return to the control level differs in statistically significant degree from the lowest recorded serum calcium mean (9 1 mg %)

The ten-day means of *serum phosphorus* all deviate upwards of the control level and the deviation seems to be approximately proportional to the time of hormonal treatment (to the aggregate hormone dosage) The outcome of this continuous increase is a mean of 4 2 mg % for the group referring to 41—75 days of hormonal treatment which differs significantly from the control level of 3 65 mg % This latest value also differs significantly from the means for the treatment periods of 1—10 11—20 and 21—30 days

The *urinary calcium* excretion mean decreases more or less uniformly from control level (265 mg per day) during the first five weeks after which it seems to remain stationary at about 125 mg per day This level is represented by the means referring to 31—40 and 41—75 days both of which differ significantly from the control level Already at 21—30 days there was a statistically nearly significant difference from the controls

The *urinary phosphorus* excretion lies below the control level in all periods considered here but no statistically significant differences can be established Immediately on commencement of hormonal treatment a decrease seems to take place from control level 790 mg per day to about 670 mg per day with another decrease at the end of 4 weeks to the level of 550 mg per day which is maintained from 6 weeks onward

The mean in the control series 2 5 Bodansky units of the *alkaline phosphatase activity* value is exceeded by all means found for the different periods in the hormonal treatment series which vary irregularly in the range of 2 9—3 3 Bodansky units (on an average 3 1 Bodansky units which is 0 6 units higher than control level)

Product of Serum Calcium and Serum Phosphorus

It was considered worthwhile to compute from the above-mentioned immediately observed values the product of serum calcium content and serum phosphorus content (in mg % squared) for each pair of such observations This quantity which is associated with the phenomena of inorganic blood chemistry through the rules governing the solubility product has been stated in the literature (*Watson Jones* 1955) to have a normal value of about 40 An excellently conforming value 39 5 was found in the present investigation as the mean for the control series

If the solubility product in the blood serum of the Ca and P ions and CO_3 anions is supposed to be constant (cf *Watson-Jones* 1955) lowered Ca-P product would imply increased carbonic acid concentration or higher acidity which seems to parallel roughly the increased activity indicated by the elevated alkaline phosphatase values

The values obtained for the Ca P product in the different groups and subgroups of the hormonal treatment series and for the entire series appear in Tables 4 and 5 and in Fig 17 The Ca P product displays during the first 3—4 weeks of hormonal treatment a lowered level of about 35 and a subsequent fairly linear return to normal level

Closer study of Table 5 and Fig 17 reveals that the immediately lowered value of the Ca P product after commencement of hormonal treatment is due solely to the abrupt fall of serum calcium As the hormone administration is kept up the serum phosphorus content gradually begins to increase but its effect on the product is compensated by the further decrease of serum calcium maintaining the said level of about 35 At last when the serum calcium content begins to increase once more both factors act in the same direction and the Ca P product returns fairly rapidly to normal

Comments

Summarizing the principal results obtained in laboratory examinations of 50 patients who received combined growth hormone and thyrotropin treatment in addition to appropriate orthopaedic therapy the following observations can be made

In the entire hormonal treatment series the average serum calcium content was lower and the serum phosphorus content higher than in the control series Urinary calcium and phosphorus excretion were lowered from the control level while the alkaline phosphatase activity was elevated These deviations from the controls amounted to highly significant differences with regard to serum calcium and urinary calcium excretion in the case of serum phosphorus a statistically nearly significant difference was noted — More detailed study aiming at elucidation of the influence on the hormonal effect exerted by various factors brought the following results

In injuries of the shaft of the femur the changes elicited in the metabolic values were most clearly evident The mean of the serum calcium content

was lowered from 10 85 mg % control level to 9 45 mg % and the urinar calcium excretion from 265 to 140 mg per day while serum phosphoru had increased from 3 65 to 4 05 mg % All three differences are statisti cally highly significant The decrease of urinary phosphorus excretio from 790 to 600 mg per day was statistically significant and the increas of alkaline phosphatase activity from 2 5 to 3 1 Bodansky units wa nearly significant

In the cases with injury of cancellous bone nearly all metabolic value displayed changes in the same direction as in the femur group but th effect was less marked and in fact virtually nil with regard to serun phosphorus and urinary calcium Here too the lowering of serum cal cium from control level was statistically highly significant

Hormonal treatment of patients with tibial injuries elicited only hal the lowering of serum calcium compared to the femur series but eve this difference was statistically significant The decrease in urinar calcium excretion was less than in the femur group and the serun phosphorus content was virtually the same as well as the alkalin phosphatase activity Urinary phosphorus excretion was higher tha the control level

On the whole the response to hormone administration can be said t have been strongest when injury of the femur was concerned less i the case of cancellous bone injury and least of all in tibial injuries Statistical analysis of the differences between effects in the differen groups as regards site of the injury is in support of this statement Comparison between subgroups made up of recent fractures on on hand and of cases with non union or delayed union on the other reveal that the response to hormonal treatment was stronger as a rule in th last mentioned than in recent fractures In particular a strong decreas of urinary calcium excretion from the control level was noted in th subgroups of non union or delayed union this can be taken to indicat greater calcium retention and storage during progress of the repai process

Investigation of the response to hormonal treatment in terms of time and thus of the total hormone quantitity administered to the patient in the series of patients treated with hormones at least 30 days revealed the following points of interest

The serum calcium content shows an immediate strong decrease from control level within not more than ten days continuing through the third or fourth week The subsequent increase still left the serum calcium below control level after 11—75 days of hormonal treatment but the maximum effect is seen to be concentrated on the first 3—4 weeks The urinary calcium excretion fell correspondingly though rather uniformly starting at control level during about five weeks and then remained stationary at only about half of the control level

The serum phosphorus content was above control level throughout the period of prolonged hormonal treatment increasing about linearly with the total hormone quantity Its highest value, which was not recorded until at a late stage differed significantly from the control level The urinary phosphorus excretion was lower than the control level throughout the investigated period Having gone down to about two thirds of the control level by the beginning of the sixth week it seems to have maintained this value at all later times

With regard to alkaline phosphatase activity elevated values were noted throughout the period of observation although the increase was fairly slight on the average 0 6 Bodansky units above control level

V DISCUSSION

It is well known that a great number of local as well as general factors exert an influence on the healing of fractures depending mainly on the kind and severity of the injury the type of the fracture its localisation vascular conditions age etc Accordingly experience has shown that it is possible in common uncomplicated fractures to estimate in advance at least the approximate time required for healing

Several attempts have been made to find some improvement of existing therapeutic expedients by which the bone repair might be stimulated This effort is readily understandable seeing that the repair process requires a prolonged time and there is still a risk that after the anticipated period delayed union or non union may be the result

The theoretical background of growth hormone and thyrotropin administration and of the effect of these hormones has been elucidated by earlier investigations among which those of *Asling et al* (1956) occupy a prominent position Existing previous investigations are mainly experimental and even today only very scanty information is available concerning the effect of growth hormone in the repair of human fractures Moreover investigations of this kind unfortunately lack the necessary control series

The present studies revealed that failure of the fracture to unite occurred when no hormonal treatment was added to appropriate orthopaedic care at a frequency nine times that observed under the effect of growth hormone and thyrotropin administration during periods of varying length

Additional light was thrown on the question of the progress of bony consolidation on the clinical level under hormonal effect and without administration of hormones by quantitative study of the callus formation in the phase when the repair process is proceeding with its greatest vigour and *activity* Except that *in the hormonal treatment series the amount of callus* at the times of two months and four months was markedly higher than in the control series the particularly noteworthy observation was made that

under hormonal effect the greater part of the callus development took place in an early phase within two months In this time the callus had reached about 3/4 of its ultimate measured size while in the controls nearly one half of the callus did not develop until during the second half of the observation period that is during the third and fourth month Since on the other hand callus formation is correlated with good blood supply (*Charnley* 1961) and with a favourable progress of bone repair as has been shown by autoradiographs with radiophosphorus and by histologic investigations this has to be considered to constitute evidence of an accelerating effect on fracture healing

Comparing both series from the viewpoint of rehabilitation the observation was made that ultimate healing was earlier in the hormonal treatment series than in the controls the gain in time being on an average nearly 2 months in fractures of the femur and 1 ½ months in tibial fractures In cases with non union or delayed union added hormonal treatment was applied in femur fractures in connection with nailing and bone graft operations In all but one case firm osseous consolidation was achieved also in two non unions and in four cases of non union of the tibia of the latter two were moreover complicated by osteitis

The changes observable in the metabolic characteristics are useful criteria reflecting the effects of endocrine agents in their clinical application Analysis of the calcium and phosphorus contents in the serum and of the urinary calcium and phosphorus excretion therefore provides a means of corroborating the effect of the hormonal treatment on fracture repair that may be seen on the clinical level Better possibilities are also created by this means for an understanding of the mode of action of these hormones of the dynamics of skeletal salt metabolism under their influence and of the optimum dosage levels

In addition to growth hormone the hormonal administration also contained thyrotropin which has been found to exert a synergistic influence on the activity of growth hormone with respect to bone It is conceivable that the daily dosage of growth hormone can be reduced with the aid of thyrotropin owing to the latter s capacity of exerting a beneficial effect on the maturation of bone (*Sissons* 1956 *Asling et al* 1956) This has been experimentally proved in investigations establishing the boosting effect of thyrotropin on growth hormone activity in the form of increased formation of new bone in the callus with simultaneous reduction of the quantity of immature tissue components fibrous tissue and fibrous cartilage as established by the *histological line sampling method* (*Koskinen* 1959 1962)

The decrease of urinary calcium excretion seems to be one of the most distinct changes in metabolic values during the progress of fracture repair under hormonal effect together with a decrease of serum calcium content In this respect reference can be made to *Henneman's et al* (1960) observations They explain the increased urinary calcium excretion noted under growth hormone effect by the fact that the hormone promotes the absorption of calcium if the calcium cannot be rapidly deposited in new bone it will appear in the urine Under the conditions existing in the present investigation the decrease of the calcium quantity found in the urine is thought conversely to indicate that calcium is stored in the organism This relative hypocalciuria thus reflects stimulation of calcium deposition and osteogenesis

The relationship between the calcium content and phosphorus content of the serum is derived from the fact that calcium phosphate and carbonate ions are present in crystalline compounds in bone and in soluble form in plasma and there is constant interchange between them (*Watson Jones* 1955) In the present investigation the product of serum calcium and serum phosphorus (both in mg %) was found to be at a level of about 35 under hormonal effect on an average 39 5 in the controls According to the literature it should be constant in normal humans at a level of 40 The lowered value in the hormonal treatment sense during the first weeks of treatment is due to the lowered serum calcium as long as there is no appreciable increase in serum phosphorus — If the calcium phosphate and carbonate ions together are assumed to obey a law of constant solubility product the lowered Ca P product can be interpreted as indicating increased acidity of the serum and this is a condition characteristic of the bone repair process and consistent with previous reports (*Stirling* 1931) The inference is that the hormonal treatment acts toward maintaining and perhaps increasing this acidity and producing optimum conditions for fracture healing

Comparison of the metabolic values found for the groups corresponding to *different sites of the fracture* (Table 1) *reveals that the hormonal effect* expressed by the changes in said values was strongest with injuries of the femoral shaft in which group the serum calcium and urinary calcium excretion had decreased and the serum phosphorus increased in statistically highly significant degree from the control level In injuries of cancellous bone the effect was considerably less with a highly significant difference from the control level only in the serum calcium value and an even inferior effect was seen in the injuries of the tibial shaft for which still a serum calcium value differing significantly from the control level was obtained

VI SUMMARY

In the present investigation concerning the effect of hormone administration on the healing of fractures roentgenological and clinical examination revealed that in the material in which appropriate conservative or operative treatment was augmented by growth hormone (STH) and thyrotropin (TSH) *given during periods of 3—10* weeks osseous consolidation took place in 62 out of 64 bone injuries The failure percentage was 1.5% (one osteitis complicated non union omitted) In the control series consisting of 30 *patients under corresponding care but without hormonal treatment osseous* union ensued in 26 while four (13.5%) failed to unite

All 22 femur fractures in the hormonal treatment series resulted in osseous union and so did ten of the 11 delayed unions or non unions of the femur while one of them failed to unite The average time required for osseous union to occur was 3.5 months in the femur fractures and 4.3 months in the cases with delayed union or non union The control series contained 20 femur fractures of which 17 achieved osseous union in 5.3 months on an average Three fractures failed to unite

Of five compound and five closed tibial fractures in the hormonal treatment series nine united delayed union resulted in one compound fracture Osseous union was achieved in all four non unions of the tibia in the series of which two were complicated by osteitis The time in which consolidation took place was 4.0 months on an average in the tibial fractures and 4.5 months in the cases with non union In the control series five of six tibial fractures consolidated in 5.5 months and one failed to unite

All 13 injuries of cancellous bone in the hormonal treatment *series consisting* of three fractures and three delayed unions of the femoral neck three trochanteric fractures one non union after trochanteric fracture and three malunited *condylar fractures united in 2—6 months* The three fractures of cancellous bone in the control series also united which took place in 1—7 months

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Comparison of the metabolic values found for the groups corresponding to different sites of the fracture (Table 4) reveals that the hormonal effect expressed by the changes in said values was strongest with injuries of the femoral shaft in which group the serum calcium and urinary calcium excretion had decreased and the serum phosphorus increased in statistically highly significant degree from the control level In injuries of cancellous bone the effect was considerably less with a highly significant difference from the control level only in the serum calcium value and an even inferior effect was seen in the injuries of the tibial shaft for which still a serum calcium value differing significantly from the control level was obtained

The question arises what may be the cause responsible for the difference in metabolic values observed between the groups of femur, cancellous bone and tibial injuries On the clinical level the extent of the available material did not render any corresponding observations possible A number of factors may have contributed to the different behaviour of the different fractures It should be noted in particular that the duration of hormonal treatment was longest in the femur group 41 days on an average the cancellous bone injuries ranging next in this respect with 35 days while the tibial injuries received hormonal treatment during an average of 25 days only Another influential factor is thought to be the mode of healing of the femur which is special in that no other long bones except the humerus have a periostal callus formation of the strength frequently seen in the femur A third factor among the most prominent ones might be the great size of the femur it is the largest long bone and the effects of its injury on the metabolism in themselves may cause changes of the described kind

Hormonal treatment continued through a prolonged period was seen to exert a more profound effect on the anabolism of bone as reflected by the *metabolic values than treatment of shorter duration This was seen on* analysis of the values in the series composed of patients who had been subjected to hormonal treatment during 30 days or longer

The changes in metabolic values with varying length of the hormonal treatment period are deserved of attention particularly as regards the urinary calcium and phosphorus excretion and the serum calcium content They account for the direction of the trend displayed by the cases with non union which received the longest treatment in comparison with other subgroups of the material (cf Table 1) The urinary calcium excretion was lower in the group of non unions of the femur than in the recent femur fractures and Table 5 reveals that particularly low urinary calcium values are characteristic just of the observation periods corresponding to prolonged hormonal treatment Similarly the low urinary phosphorus excretion in the non-union groups is consistent with the fact that the lowest urinary phosphorus values in Table 5 are found in the observation periods of 31—40 and 41—75 days

The strength of the hormonal effect varies with the duration of hormonal treatment the maximum effect on serum calcium being concentrated on the first 3—4 weeks while the decrease of urinary calcium excretion was approximately uniform during the first five weeks with a subsequent stationary level It is obvious that full effect of the hormonal treatment has been attained within about 5—6 weeks from its commencement this is the

optimum period for bone repair under hormonal treatment if the treatment is started in an early phase of the reconstruction process Also hormonal treatment instituted at a later time may exert a beneficial effect but the results are not equally reliable

On the strength of the present results the observation can be made that growth hormone and thyrotropin possess an osseous anabolic effect and their administration can be beneficially employed as an aid to appropriate conservative or operative orthopaedic treatment to promote bone repair in human patients and to shorten their time of recovery Especially in cases in which delayed union is anticipated or non union has already ensued and operative treatment is undertaken it seems to be possible to aid the healing of the bone by means of these consolidation promoting substances

VI SUMMARY

In the present investigation concerning the effect of hormone administration on the healing of fractures roentgenological and clinical examination revealed that in the material in which appropriate conservative or operative treatment was augmented by growth hormone (STH) and thyrotropin (TSH) given during periods of 3—10 weeks osseous consolidation took place in 62 out of 64 bone injuries The failure percentage was 1 5% (one osteitis-complicated non union omitted) In the control series consisting of 30 patients under corresponding care but without hormonal treatment osseous union ensued in 26 while four (13 3%) failed to unite

All 22 femur fractures in the hormonal treatment series resulted in osseous union and so did ten of the 11 delayed unions or non unions of the femur while one of them failed to unite The average time required for osseous union to occur was 3 5 months in the femur fractures and 4 3 months in the cases with delayed union or non union The control series contained 20 femur fractures of which 17 achieved osseous union in 5 3 months on an average Three fractures failed to unite

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All 13 injuries of cancellous bone in the hormonal treatment series consisting of three fractures and three delayed unions of the femoral neck three trochanteric fractures one non union after trochanteric fracture and three malunited condylar fractures united in 2—6 months The three fractures of cancellous bone in the control series also united which took place in 1—7 months

Quantitative radiographic study of the callus in femur fractures revealed that in the hormonal treatment series the callus 2 months and 4 months after the trauma or surgical intervention was about twice the size of the callus at corresponding times in the control series It was seen that the callus of the hormonally treated patients was not only greater in absolute quantity but especially was formed and obtained its maximum size at an earlier time than in the controls

The following main results were recorded in the study of the metabolic values found in 50 cases of the hormonal treatment series and in 13 controls Several of the effects observed under hormonal treatment were found to be statistically significant

The mean serum calcium content of the entire hormonal treatment series decreased from control level 10.85 mg % to 9.55 mg %, and the serum phosphorus content increased from 3.65 mg % control level to 3.95 mg % The urinary calcium and phosphorus excretion values decreased (from 265 to 165 mg per day and from 790 to 690 mg per day respectively) indicating retention of calcium and phosphorus

The metabolic effect was strongest in the group of injuries of the femoral shaft less marked in injuries of cancellous bone and least in injuries of the tibial shaft Regardless of the site of injury the metabolic response to hormonal treatment was stronger in cases of non union or delayed union than in those involving recent fractures indicating calcium retention at a higher rate in the first mentioned

The following particulars were noted in an analysis of the response to hormonal treatment with different durations of hormone administration The serum calcium content fell abruptly within the first ten days and maximum response was concentrated on the first 3—4 weeks In spite of its subsequent rise the serum calcium level remained below that of the controls even after 40—75 days of hormone administration The urinary calcium excretion decreased uniformly during about five weeks after which it remained at a level about one half of that in the control series The serum phosphorus content was elevated from control level at all times its increase appearing to be proportional to the total quantity of administered hormones with its highest value after hormonal treatment during 40—75 days The urinary phosphorus excretion displayed a level below the controls in all periods of observation from about five weeks onward it seemed to be stationary at about one third of the control level Alkaline phosphatase activity was elevated though only in slight degree from the control level at all observed times

VI SUMMARY

In the present investigation concerning the effect of hormone administration on the healing of fractures, roentgenological and clinical examination revealed that in the material in which appropriate conservative or operative treatment was augmented by growth hormone (STH) and thyrotropin (TSH) given during periods of 3—10 weeks, osseous consolidation took place in 62 out of 64 bone injuries. The failure percentage was 1.5% (one osteitis complicated non-union omitted). In the control series consisting of 30 patients under corresponding care but without hormonal treatment, osseous union ensued in 26, while four (13.5%) failed to unite.

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Of five compound and five closed tibial fractures in the hormonal treatment series nine united; delayed union resulted in one compound fracture. Osseous union was achieved in all four non-unions of the tibia in the series, of which two were complicated by osteitis. The time in which consolidation took place was 4.0 months on an average in the tibial fractures and 4.5 months in the cases with non-union. In the control series five of six tibial fractures consolidated in 5.5 months, and one failed to unite.

All 13 injuries of cancellous bone in the hormonal treatment series, consisting of three fractures and three delayed unions of the femoral neck, three trochanteric fractures, one non-union after trochanteric fracture and three malunited condylar fractures, united in 2—6 months. The three fractures of cancellous bone in the control series also united, which took place in 4—7 months.

VII ZUSAMMENFASSUNG

In der vorliegenden die Wirkung von Hormonverabreichung auf das Heilen von Knochenfrakturen betreffenden Untersuchung ergab die rontgenologische und klinische Untersuchung dass in dem Material dessen Patienten zuzuglich sachgemasser konservativer oder operativer Pflege Wachstumshormon und Thyrotropin wahrend Perioden von 3—10 Wochen Dauer erhielten knocherne Konsolidierung in 62 von 64 Knochenverletzungen stattfand Die Behandlung versagte in 1 5% (unter Auslassung eines Falls von Pseudarthrose durch Knochenentzündung kompliziert) In der Kontrollreihe bestehend aus 30 Patienten in entsprechender Pflege, jedoch ohne Hormonbehandlung wurde knocherne Vereinigung in 26 Fallen verzeichnet wahrend sie in 4 Fallen (13 5%) ausblieb

Samtliche 22 Oberschenkelfrakturen in der Hormonbehandlungsreihe endigten in knocherner Vereinigung und gleichfalls 10 der 11 Falle mit verzogerter Vereinigung bzw Pseudarthrose Die im Durchschnitt zur knohernen Vereinigung benotigte Zeit belief sich bei den Oberschenkelfrakturen auf 3 5 Monate und bei den Fallen mit verzogerter Vereinigung oder Pseudarthrose auf 4 3 Monate Die Kontrollreihe enthielt 20 Oberschenkelschaden von denen 17 im Verlauf von im Durchschnitt 5 3 Monaten knocherne Konsolidierung zeigten Bei drei Frakturen blieb die Vereinigung aus

Von 5 offenen und 5 geschlossenen Tibiabruchen in der Hormonbehandlungsreihe entstand knocherne Vereinigung in 9 bei einer offenen Fraktur was das Ergebnis verzogerte Konsolidierung Knöcherne Vereinigung wurde bei allen 4 Pseudarthrosen in der Tibiareihe erzielt von denen zwei durch Knochenentzundung kompliziert waren Die zur Konsolidierung notwendige Zeitspanne war bei den Tibiafrakturen 3—6 Monate im Durchschnitt 4 0 Monate und bei den Fallen mit Pseudarthrose war sie 4—8 Monate im Durchschnitt 4 5 Monate In der Kontrollreihe ergab sich bei 5 der 6 Tibiafrakturen Konsolidierung in 4—7 Monaten im Durchschnitt 5 5 Monate wahrend Vereinigung in einem Fall ausblieb

Growth hormone and thyrotropin have been concluded to possess an osseous anabolic effect Their administration is thought to be beneficial as an aid to appropriate orthopaedic treatment promoting the healing of fractures and shortening the time required to achieve osseous consolidation especially in cases in which delayed union is anticipated or non union is an established fact

auf etwa halber Hohe des Kontrollspiegels Der Serum Phosphorgehalt lag zu allen Zeiten etwas uber dem Kontrollspiegel und zwar schien seine Zunahme der Gesamtmenge von verabreichtem Hormon proportional zu sein mit einem höchsten Wert nach 40—75tägiger Hormonbehandlung Die urinare Phosphorexkretion zeigte zu allen Zeiten einen unter dem der Kontrollreihe liegenden Spiegel von etwa 5 Wochen an schien er bei etwa einem Drittel des letztgenannten Werts stehenzubleiben Die alkalische Phosphataseaktivitat war zu allen Zeiten dem Kontrollspiegel gegenuber erhoht wenngleich nur in geringem Mass

Es wird gefolgert dass Wachstumshormon und Thyrotropin einen ossealen anabolischen Effekt entfalten Ihre Verabreichung durfte als Zusatz zu sachgemasser orthopadischer Pflege zu empfehlen sein indem sie die Heilung von Frakturen fordert und die zur Erreichung knocherner Konsolidierung erforderliche Zeit verkurzt dies insbesondere in Fallen in denen verzögerte Vereinigung zu erwarten ist oder tatsachliche Pseudarthrose vorliegt

VIII ACKNOWLEDGEMENTS

This investigation was carried out in the Clinic for Orthopaedics and Traumatology, University of Helsinki, whose Chief, Professor K. E. Kallio, M.D., has kindly permitted the author to use the present material. For this I feel deeply obliged to him, and equally for his valued support during progress of the work.

My sincere thanks are due to Professor Unto Uotila, M.D., Chief of the Department of Forensic Medicine, University of Helsinki, to whom I owe *the instigation to embark on research concerning hormones in bone repair.*

The Physician of the Clinic's Laboratory Department, University Lecturer R. Gordin, M.D., is deserved of my gratitude for assistance given in the laboratory work. I also wish to give expression to my appreciation of all that has been done in aid of this work by my other colleagues and by the nurses of the Clinic.

Mr. U. Attila, M.Sc., has given his help in the statistical treatment and tabular and graphical presentation of the results, and he has translated the manuscript.

This work has been aided by a grant from the Sigrid Juselius Foundation. My understanding of its subject was essentially deepened by my attendance of the Gordon Research Conference on the Chemistry, Physiology and Structure of Bones and Teeth in Meriden, N.H., U.S.A., on July 9—13, 1962, which was made possible by a grant received form the Trustees of the Conference.

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ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM no 63

FROM THE CLINIC FOR ORTHOPAEDICS AND TRAUMATOLOGY
UNIVERSITY OF HELSINKI (HEAD PROFESSOR K E KALLIO)

FRACTURES OF THE TIBIAL CONDYLES

BY

KAUKO A. SOLONEN

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MUNKSGAARD
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FRACTURES OF THE TIBIAL CONDYLES

Fractures of the tibial condyles which damage the largest human joint are of great importance and their treatment is difficult The principal aim of the treatment should be perfect function of the knee joint i e the knee should become stable without valgus or varus deformity, extension should be complete and flexion as free as possible According to various clinicians this goal ist best achieved either by 1) conservative procedures alone 2) chiefly operative procedures or 3) conservative or operative methods as indicated in the individual cases

The following investigation is based on a follow up examination of fractures of the condyles treated in our clinic during the period 1951 to 1960 My aim has been personally to evaluate the end results of the treatment of this important group of injuries and the argumente for and against the different procedures used

Material

A total of 77 patients with fractures were treated Two patients died during hospitalization both of pulmonary embolism 53 patients (70 per cent) reported for follow up examination and were all examined personally by me Of the patients 26 were men and 27 women

The follow up period ranged from 11 to 2 years Of the patients followed up 34 had fracture of the lateral condyle (age 16 to 78

years) 9 of the medial condyle (age 27 to 69 years) and 10 bicondylar fracture (age 37 to 62 years) At the time of the accident the age distribution of these patients was 26 patients 16 to 50 years, 27 patients 51 to 78 years the average age at the time of the accident being 50 years

Aetiology and mechanism of trauma

There is no reason to call these fractures bumper fractures since, in the majority of cases the mechanism does not involve the impact of a bumper The commonest it is true is a direct mechanism of origin i e the medial or lateral side of the extended or slightly flexed knee is struck with sudden force The fracture may also be the indirect result of stumbling or falling from a height, the fracturing force being directed vertically from the femoral condyle towards the tibial plateau Injuries to the lateral tibial condyle are commoner since one leg protects the other from trauma exerted from the medial side, the protecting leg thus receiving the valgus producing injury which damages the lateral condyle

There are two divergent opinions as to the mechanism of monocondylar fracture WATSON JONES (1955) and SMILLIE (1962) are among those who believe that lesion of the collateral ligament on the other side is necessary before the condyle can fracture as a result of direct mechanism Injury to the tibial collateral ligament is commoner This is because of the direction of violence and because the whole ligament is taut when the knee is extended and one part of it remains taut in all flexion positions of the knee (BRANTIGAN & VOSHELL 1941—1943 DEPALMA 1954) The anterior cruciate ligament is likewise readily injured since its function is very similar to that of the medial collateral ligament and this ligament too is taut in extension and flexion except at the very beginning of flexion (FICAT 1962) The mechanism of the trauma is such that the lateral collateral ligament is less often damaged than the two former MARTIN s experimental investi

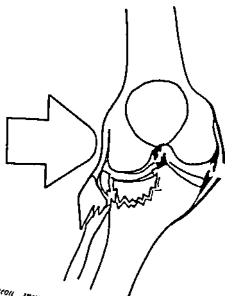


Fig 1 Simultaneous injury of the ligament and fracture of the condyle

gations (1960) argue in favour of simultaneous injury to the collateral ligament and fracture of the condyle (fig 1) This is also my opinion

There are also those who believe that fracture of the opposite condyle only occurs when the collateral ligament escapes injury (BANCROFT & MURRAY 1945 among others) i e there will be either rupture of the collateral ligament or fracture of the opposite condyle

Lesion of a ligament seems seldom to be diagnosed in connexion with fracture of a condyle

From the point of view of aetiology the present material can be grouped as follows

TABLE 1 *Aetiology*

Fracture	1 Run over by vehicle	2 Fell from motor cycle or bicycle	3 Tripped when walking	4 Fell or jumped from great height	5 Direct trauma to the side of the knee*	Total
Fracture of the lateral condyle	17	3	7	4	3	34
Fracture of the medial condyle	1	3	4	—	1	9
Bicondylar fracture	2	3	1	3	1	10
Total	20	9	12	7	5	53

*) The great majority of fractures of column 1 are known to have occurred in this way

Patho anatomy

Monocondylar fracture occurred in 87 per cent and bicondylar in 13 per cent of the cases of the present series

Of the monocondylar fractures 55 (82 per cent) were fractures of the lateral condyle and 12 (18 per cent) of the medial condyle A survey of the literature shows that in ENDER's (1955) series of monocondylar fractures the lateral condyle was involved in 89 75 per cent and the medial condyle in 10 24 per cent bicondylar fracture being present in 16 72 per cent of cases HOLLF & HART's (1958) corresponding figures were of the monocondylar fractures 77 7 per cent were fractures of the lateral condyle and 22 2 per cent of the medial condyle the bicondylar fractures constituted 38 per cent of the entire series CORNELL & HARDY (1929) reported the following percentages fractures of the lateral condyle 76 per cent and of the medial condyle 24 per cent of monocondylar

fractures the bicondylar fractures constituting 9 per cent (intercondylar 5 per cent)

There are many suggestions for a more detailed grouping of fractures according to their type (HULTEN 1929 MIKKELSEN 1933 BADGLEY & O CONNOR 1952 DEPALMA 1954 ENDER 1955 SLEE 1955 FICAT 1962 WELLER & KOHNLEIN 1962 and others) In clinical work a simple division into three or four type groups would seem adequate although it is obvious that few fractures strictly conform to one type and that mixed types are the commonest The better a fracture can be visualized the less typical it usually proves and the harder to classify

The cases of the present series can be classified as follows

1 15 split fractures comprising 6 fractures of the lateral and 9 of the medial condyle (Fig 2 A)
2 20 compression fractures all of the lateral condyle with compression sometimes of the anterior sometimes of the posterior and sometimes of the central portion (Fig 2 B)
3 10 bicondylar fractures (Y V T fractures) all of them more or less comminuted (Fig 2 C)
4 8 marginal fractures all of the lateral condyle Most authors pay no attention to these fractures Yet they are of great importance and of particular diagnostic significance Some of them seem to have occurred by avulsion or are split or compression fractures (Fig 2 D)

Accessory injuries

In connexion with fracture of the condyles there are often other simultaneous injuries besides the ligamentous injuries already mentioned i e rupture of the patellar ligament often rupture of a meniscus fracture of the head of the fibula sometimes accompanied by injury to the peroneal nerve injury to the large vessels and sometimes as a result of violent trauma other fractures

In the present series there was rupture of the medial collateral ligament in 4 cases but only in one case had the rupture been



Fig. 7 The main types of fracture of the condyle A Split fracture B Compression fracture C Bicondylar fracture D Marginal fracture

repaired at the time of the primary treatment CAVE (1948) is against primary repair of the ligament in cases of fracture of a condyle while most other authors maintain silence on this point

Lesions of the cruciate ligament had not been primarily recorded

Rupture of a meniscus was mentioned and there was also mention of the removal of the meniscus on the side of the fractured condyle in 6 of the 12 operated knees Although many authors (DEPALMA CHARNLEY 1961 LEADBETTER & HAND 1940 BANCROFT & MURRAY BURKE DE LA CAMP and others) recommend removal of the meniscus as part of the operative treatment and in order to improve the view some even advocate it as a routine measure I wholeheartedly agree with PALMER (1951) ENDER (1955) and BOHLER (1957) that the meniscus should be removed only when it is irreparably injured After it has been partly freed it should be replaced and sutured to aid retention of the fragments and to protect the joint surface of the femur from the roughness of the opposing surface

In the present series there was fracture of the fibula head in 6 cases in 2 cases in conjunction with fracture of the lateral condyle in 2 of bicondylar compression fracture and in 2 split fractures of the medial condyle In the latter cases the fracture of the fibula head is actually an avulsion injury of the collateral ligament

Injuries to the peroneal nerve were not observed

Rupture of the tibiofibular joint may also occur no such ruptures were noted in the present series

There were no ruptures of the patellar ligament among the present cases

Diagnosis

In the era of modern radiology diagnosis is not difficult To determine the degree of severity of the fracture may prove difficult however Tomography is sometimes necessary to demonstrate a depressed fragment for instance and the projection is

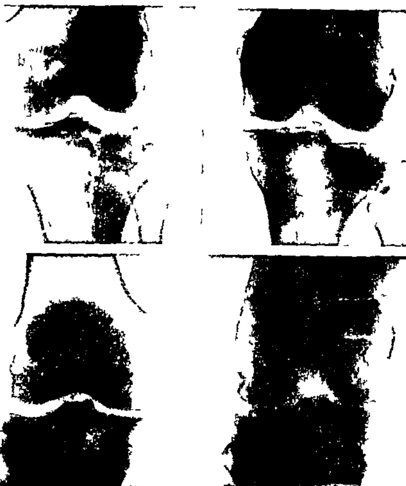


Fig 3 The significance of projection in radio raphy In the radiograms on the left a dislocation requiring reposition is not demonstrated while such a dislocation is evid nt in the pictures on the right

often of conclusive importance (fig 3) although I have not seen mention of this in the literature

Treatment

Although there are divergent opinions as to whether conservative or operative treatment of these fractures is superior the

importance of early mobilization is universally acknowledged (HALDEMAN 1938 CAVE 1948 MAISEL & CORNELL 1948 CORNELL & HARDY 1950 PALMER 1951 LINDHOLM 1954 APLEY 1956 HOHL & LUCK 1956 HOLLE & HART 1958 DEPARC & FICAT 1960 ROMBOLD 1960 CHARNLEY 1961 REIDEL & al 1962) By early however these authors mean sometimes weeks sometimes days

TABLE 2. *Primary treatment*

Fracture	Treatment		Total
	Conservative	Operative	
Split fractures	11	4	15
Compression fractures	14	6	20
B condylar fractures	7	3	10
Marginal fractures	7	1	8
Total	39	14	53

In more than half the cases referred to the group of conservatively treated fractures the treatment consisted of immobilization in a plaster bandage after reduction or attempts at reduction while in a few cases the patient was merely confined to bed In less than half the cases the conservative treatment consisted of mobilization (KALLIO 1960) after or without correction of the position of the fragments (fig 4) The average duration of immobilization in plaster cast or mobilization in suspension was 8 weeks and the patient was then allowed to be up without weight bearing for an average of 4 weeks after which weight bearing was as a rule begun

Operative treatment was resorted to in some instable cases and in cases in which it was believed that better results would be obtained by surgical intervention than by the conservative treatment first employed In most cases operative reduction was followed by plaster immobilization but in a few cases active mobilization was begun immediately In the last few years this mobilization method has been used with advantage in numerous cases (Fig 5 and 6)

Fig 4 Mobilization traction In no case was there any significant detrimental effect of the traction nails

A

B

Fig 5 Open reduction was carried out on this fracture (A) and since it was comminuted stable fixation was not possible The fragments were fitted together with chromic catgut sutures Active mobilization as illustrated in fig 6 was commenced on the first postoperative day The second picture (B) shows the result after two years

Results of treatment

When the results are evaluated it should be observed that the treatment was given by many surgeons with varying experience A less experienced surgeon on duty often had to carry out the important primary treatment There had also been great variations in the details of the treatment

Using HOHL and LUCK s (1956) criteria of grading*) the final results were as follows

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*) CRITERIA OF GRADING USED IN THE FOLLOW UP STUDY OF 227 TIBIAL CONDYLAR FRACTURES

Anatomic Grad	
Excellent (All of the following) 1 Normal valgus within 5 degrees 2 Restoration of displacement within 3 millimeters 3 No degenerative joint changes	*Good* (Not more than one of the following) 1 Valgus of more than 5 degrees 2 Minimal degenerative joint changes
Fair (Not more than two of the following) 1 Valgus deformity of more than 10 degrees 2 Moderate degenerative joint changes 3 Lack of fracture reduction	*Poor* (All of the following) 1 Moderate or severe degenerative joint changes 2 Lack of fracture reduction 3 Valgus deformity of more than 10 degrees
Functional Grade	
Excellent (All of the following) 1 Full extension of the knee 2 120 degrees range of motion or more 3 No abnormal abduction rocking 4 Normal strength and endurance 5 Occasional ache permissible	*Good* (Not more than one of the following) 1 Lack of knee extension beyond 170 degrees 2 Excessive lateral mobility 3 Mild aching each day 4 90 degrees total range of motion 5 Weakness or easy fatigue
Fair (Not more than two of the following) 1 Lack of knee extension more than 170 degrees 2 75 degrees range of motion 3 Discomfort for ordinary activity 4 Excessive lateral mobility	*Poor* (Three or more of the following) 1 Lack of useful motion (less than 75 degrees) 2 Unable to work 3 Pain in all activity 4 Excessive lateral mobility

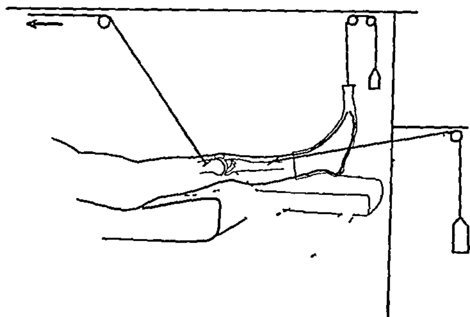


Fig 6 The method of postoperative mobilization in a specially constructed bed The femoral counter fraction was thought important to help the patient to maintain the thigh in the same position the whole time in the beginning

A Results in the different types of fracture

In split fractures both anatomically and functionally excellent or good results were obtained in 10 out of 15 cases (67 per cent)

In compression fractures an anatomically good result was obtained in 5 cases only (25 per cent) but functionally the result was excellent or good in 12 cases (60 per cent)

In marginal fractures the anatomical result was always at least good, but the functional result was excellent or good in 6 out of 8 cases only (75 per cent) The cause was ligamentous insufficiency

B Results of different methods of treatment

When the results obtained with different methods of treatment are compared we find that immobilization gave an excellent or

good result anatomically in 68 per cent of cases but functionally in only 52 per cent of cases Mobilization gave an excellent or good result anatomically in 60 per cent and functionally in 73 per cent of cases After operative treatment an excellent or good result was obtained anatomically in 15 per cent and functionally in 85 per cent of cases

It is readily understandable that in these intra articular fractures immobilization gave a higher proportion of poor results It was surprising however to find that the results of operative treatment tended to be anatomically unsatisfactory although functionally good (fig 7) The unsatisfactory anatomical results of operation confirm the opinion that these fractures require technically exacting operations The best results were achieved in the cases treated with early active mobilization after operative reduction

The above figures do not give any information as to which method is the best The indications for the different methods are different but no doubt another choice could have been made in many cases

C Comparison of the results of fractures of the medial and lateral condyles

When the end results of treatment of similar fractures of the medial and lateral condyles (i e split fractures) are compared we find that in fractures of the medial condyle which from the point of view of weight bearing are more important better results were obtained The result was excellent or good in eight out of nine cases as compared with a good result in three out of six cases of fracture of the lateral condyle

D Results in various age groups

The functional results were best in the youngest and the oldest patients the result was excellent or good in 63 per cent of the age group 16 to 30 years in 53 per cent in the age group 31 to 50 years and in 74 per cent in the age group 51 to 78 years

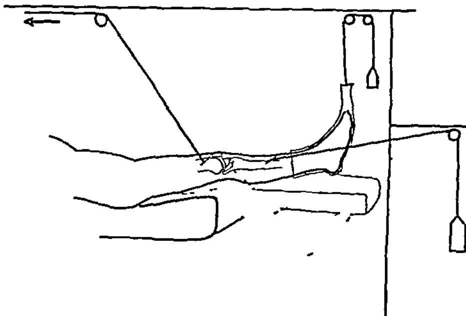


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Fig 8 Unreduced fracture since the patient refused operation Functionally the result was good 3 years later (B) (male years)

zation is clearly a factor that greatly impairs the functional result As would be expected one reason for poor end results is unsatisfactory correction of the position of the fragments for instance in cases in which a depressed central fragment has remained unreduced Reduction is sometimes rendered impossible by severe wound complications or by a critical general condition of long duration An unrepaired ligamentous lesion is sometimes the cause of a poor result as is also secondary arthrosis although the latter is actually part of the poor result To what extent the degree of severity of the arthrosis depends on the method of treatment could not be concluded from the present series The achievement of good function despite a poor anatomical result is puzzling but this phenomenon is well known in cases of arthrosis deformans for instance in which the subjective symptoms are not directly correlated with the degree of deformity

Ligament injuries

At follow up examination insufficiency of 4 lateral and 8 medial ligaments was observed (23 per cent of the cases). One case of rupture of the medial collateral ligament primarily diagnosed but untreated was symptom free at follow up There was insufficiency of the lateral collateral ligament in 3 cases of fracture of the lateral condyle and 1 of the medial condyle At follow up the medial collateral ligament was lax in 7 cases of fracture of the lateral condyle and in 1 bicondylar fracture Whether in these cases there is always an unhealed ligamentous rupture dating from the time of the fracture or whether sometimes a stretching of the ligament has been caused by a change in the bony joint structure could not be concluded Yet the condyle was depressed in only a few of these cases The fact that a depressed condyle is probably the cause of subsequent insufficiency of the collateral ligament should argue in favour of careful reduction

At follow up clear insufficiency of the anterior cruciate ligament was observed in 5 cases and of the posterior cruciate ligament in 1 case all in extremities with powerful muscles

Besides these clear cases of damaged ligaments instability of the knee was the most serious complaint of many patients, although clinically threre was nothing to indicate lesion of a ligament

In the insignificant marginal fractures insufficiency of the collateral ligament cannot depend on deformity of the bone However in 2 out of 8 (25 per cent) such fractures there was indisputable insufficiency of the medial collateral ligament and in one of them in addition laxity of the anterior cruciate ligament (*fig 9 and 10*) Thus the diagnostic value of these »insignificant fractures» as indicators of ligamentous lesions is obviously considerable

There were probably primarily a greater number of ruptures of collateral ligaments than were found at follow up This is indicated by the fact that a ligamentous rupture had healed without any *special treatment and that these ligaments are known* sometimes to heal after immobilization alone

In many knees in which follow up showed that the condyle



Fig 9 The fracture is insignificant b it there was sim ltaneous tearing of the medial collateral l gament and the anterior cruciate ligament



Fig 10 In this knee bes des fractu e of the lateral condyle there was complete rupture of the medial collateral ligament

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Fig 12 A fa p imary res lt (A) after immobilization bit 2 1 years later (B) the knee was poor as a result of aseptic ne rosis (female 39 years)

had remained depressed, no pathological mobility could be detected This might be explained by the presence of fibrous or fibrocartilaginous tissue filling the depression (HOHL & LUCK, DUPARC & FICAT) and possibly by a sufficient support to the femur provided not only by the tissues mentioned but also by the non depressed area of the joint surface

Meniscus lesions

At follow up there was reason to suspect rupture of a meniscus in split fractures of one medial and one lateral condyle treated conservatively in which the end result with regard to the fracture was excellent but in which locking of the joint indicated a sequel of injury to the meniscus In no case in which the partly freed meniscus was replaced and sutured were there late complications arising from the lesion of the meniscus

DISCUSSION AND CONCLUSIONS

Examination of this series and the experience gained in the present day treatment of similar fractures have confirmed the opinion that to achieve perfect function of a f r a c t u r e d k n e e j o i n t the anatomy of the joint should be restored as carefully as possible When a radiogram is interpreted it should be remembered that the joint cartilage menisci ligaments and joint capsule are also essential parts of the joint Reduction of the fragments is important and mostly possible Retention however may cause difficulties There are those who advocate stable fixation of fragments Often this cannot be perfectly achieved but that should not prevent otherwise indicated operative reduction since absence of stable fixation can as a rule be compensated by suitable after treatment allowing controlled collapse of the fragments only to the extent that this can occur without reluxation (fig 5 and 6) Even a bicondylar fracture can be mobilized from the beginning and yet preserve the favourable position achieved at reduction and good consolidation may be obtained despite the fact that this procedure is in pointed contrast to the traditional principles of fracture surgery (Fig 11) There was not one case of non union in cases thus treated Conservative treatment and in particular mobilization treatment is indicated when reduction is unnecessary i e when the total depression of the condyle is only a few millimetres or when the depression or elevation of separate fragments is insignificant or when the fracture is so complicated or so fragmented that operative reduction is hopeless or prevented and

had remained depressed no pathological mobility could be detected This might be explained by the presence of fibrous or fibrocartilaginous tissue filling the depression (HOHL & LUCK DUPARC & FICAT) and possibly by a sufficient support to the femur provided not only by the tissues mentioned but also by the non depressed area of the joint surface

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SUMMARY

A follow up examination was made of 53 patients 2 to 11 years after fracture of the tibial condyle

The majority of the fractures were sustained in traffic accidents

Among the patients the two sexes were more or less equally represented

Ages ranged from 16 to 78 years the average age being 50 years

The methods of treatment were (reduction +) immobilization (reduction +) mobilization or operative treatment (+ immobilization) + mobilization

The best results were obtained in the group of split fractures The results in compression and bicondylar fractures were equally good Small marginal fractures are diagnostically important since they often indicate ligamentous rupture

Operative and mobilization treatment were the methods that produced the best functional results

An anatomically good primary result is usually followed by a functionally good end result Consolidation always takes place

Operation is difficult and requires considerable experience and an atraumatic technique

The method of treatment must be chosen to suit each individual case In some instances conservative and in others operative treatment is called for Active mobilization is always indicated either as the principal method of treatment or as the earliest possible continuation of some other method

in old persons even on slighter indications The value of operation without opening of the joint a procedure which has sometimes been advocated is debatable The intra articular damage is always larger than is radiographically evidenced — Operative repair of the fracture i e surgery of the joint like surgery of the hand must be atraumatic Otherwise neither rapid postoperative mobilization nor a successful end result can be expected The reduced fragments can be fixed in many different ways with wires sutures bolts or screws It is often necessary to support the depressed fragment with osseous transplants, either autogenous or of conserved bone It is important to make sure by means of radiograms taken during the operation that the depressed condyle has been sufficiently elevated Otherwise it may happen that although the joint surface is perfect the condyle remains depressed There is reson to remove small loose fragments which are doomed to *necrosis* for the space they occupy will be filled with fibrous tissue or fibrocartilage and even with hyaline cartilage (HALDIMAN 1938 HOHL & LUCK) Menisci should be removed only if they are damaged There is reason to repair ligament ruptures in these cases as well as in the case of simple ligament lesion The following treatment must be adapted accordingly Intensive active motion is always called for either from the very beginning or later depending on the method of treatment and the kind of accessory lesions To prescribe absolute rules for treatment is not possible In each individual case many more factors than the type and condition of the local fracture must ne considered The final aim — good function — presupposes restoration of the shape of the joint in suitable cases atraumatic repair of damaged parts of the joint and always early active mobilization

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In the author's opinion the most important observation in the present investigation was that ligamentous damage or secondary laxity of ligaments as a result of a persisting osseous deformity are often the cause of an unsatisfactory late result. In suitable cases lesions of the ligament then require to be repaired and the other treatment must be adapted accordingly.

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM 64

From the Orthopedic Clinic Royal Medical School Umeå Sweden
Head Professor Lennart Hult M D

THE VENOUS RETURN FROM THE LOWER LEG IN HEALTH AND IN CHRONIC VENOUS INSUFFICIENCY

A Synthesis

by

CARL C ARNOLDI

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MUNKSGAARD

THE VENOUS RETURN
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MUNKSGAARD
1964

Contents

The venous return from the lower extremity against the hydrostatic forces still presents a number of problems awaiting their solution We cannot truthfully say that the mechanism of the healthy venous pump is wholely understood and it is evident to any student of venous pathology that the difficulties increase when it comes to the evaluation of the venous pump in patients with chronic venous insufficiency

During the last few decades some important investigations have however been published which throw some light on the venous circulation in the lower extremity in health as well as where the venous return is impaired These reports appear scattered and often unrelated in the literature

The *first object* of the present paper will therefore be to collect and review some of the pertinent reports which have a bearing on the understanding of the conditions for the venous return

The function of the venous pump in the lower leg has been studied phlebographically by the author by means of a standardized functional method (dynamic intraosseous phlebography (Arnoldi & Bauer 1960 a 1960 b Bauer & Arnoldi 1960) and an analysis of the findings was published by Arnoldi (1961 a 1961 b) The *second object* of the present study will be to compare the phlebographic findings — and the resulting conception of the venous pump — with the information found in the literature regarding the physiological conditions for the venous return in the hope that such a synthesis may increase our knowledge and understanding of the problems of chronic venous insufficiency

Sound therapeutic principles must be based upon a definite conception of pathology This is as true in venous insufficiency as in other branches of medicine The author s conception of the pathology of chronic venous insufficiency is the basis for the *third object* of this

paper namely a discussion of the therapeutic consequences of these ideas

As is so often the case in medicine the present analysis gives rise to more problems than it set out to solve and the *fourth object* has thus been to show some of the unsolved questions in need of further investigation

PART I
OBSERVATIONS ON ANATOMIC STRUCTURES AND PHYSIOLOGICAL CONDITIONS IN THE LOWER LEG

CHAPTER I
THE VEINS OF THE LOWER EXTREMITY

When considering the veins of the lower extremity it is practical to distinguish between three systems the subcutaneous the subfascial and the communicating veins

The subcutaneous veins The saphenous veins and their tributaries drain most of the skin and subcutis of the lower extremity and part of the abdominal wall They are as a rule found near the deep fascia but in adipose extremities the veins lose their close relation to the fascia and are found embedded in loose fatty tissues

It is generally assumed that about ten per cent of the venous return from the lower extremity take place through the subcutaneous veins The blood flow through the saphenous system is partly upwards partly central through the communicating veins into the deep veins The subcutaneous veins are equipped with valves which under normal conditions prevent a distal flow of blood The number of valves vary within wide limits

The skin and subcutaneous tissues in the malleolar regions are as a rule drained by the tributaries of the ankle perforating veins which may or may not anastomose with the saphenous trunks Where the ankle perforating veins form a separate drainage system it may be regarded as a third saphenous system *(Arnoldi 1958)*

The subfascial veins The deep veins of the lower extremity drain the structures under the deep fascia The numerous tributaries from bones tendons and muscles drain into a system of deep venous trunks In the lower leg each musculo fascial compartment contains a set of deep trunks placed as vv comites alongside the arteries *(Fig 1)* The anterior and posterior tibial and the peroneal veins coalesce in the upper part of the leg to form the popliteal vein which at a somewhat higher level is joined by the gastrocnemial veins

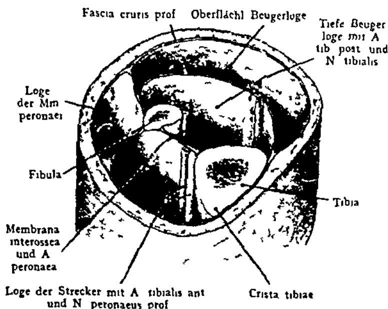


Fig 1 (From Corning Lehrb top Anatomie) Schematic cross section through the lower leg The four musculo fascial compartments are shown together with nerves and arteries The deep veins are placed as vv comites close to the arteries

The central stem continues upwards in the adductor canal as the superficial femoral vein and is joined by the deep femoral vein in the upper part of the thigh The common femoral vein continues above the inguinal ligament as the external iliac vein The deep femoral vein drains a set of musculo fascial compartments in the thigh

The relations of the deep veins will be considered in Chapter II

The communicating veins It is customary to distinguish between two types of communicating veins indirect and direct The indirect communicating veins are small but very numerous and are called indirect as they pass from a subcutaneous vein to a muscular vein in the leg or thigh The direct communicating veins are fewer and relatively constant in their position They are somewhat larger than the indirect communicating veins and they connect the subcutaneous veins directly with the deep trunks

The most important groups of direct communicating veins are fairly constant in their position On the thigh they connect the internal saphenous vein or its tributaries with the femoral vein in Hunter's canal In the lower leg a medial group is found near a line connecting

a point on the medial border of the tibia at the level of the middle of this bone with a point below and slightly posterior to the internal malleolus A lateral group is generally found in front of the lateral border of the Achilles tendon The communicating veins in the lower two thirds of the leg are generally called ankle perforating veins

While the anatomy of the communicating veins of the lower leg has been known for more than a hundred years it is especially through the work of Cockett (1953) that the importance of the medial and lateral ankle perforating veins in the pathology of the venous leg ulcer has been established

The communicating veins are equipped with valves at the entrance into the deep veins which under normal conditions only allow a central flow from the subcutaneous into the deep veins

CHAPTER II
THE MUSCULO VENOUS RELATIONS IN THE LEG AND LOWER THIGH

The musculo venous pump with which we are concerned at present consists of the popliteal vein the anterior and posterior tibial veins and the peroneal vein together with the muscular tributaries which emerge into these veins The muscles of the leg which are drained by these vessels are arranged in three compartments (Fig 1) the anterior which contains the tibialis anterior extensor hallucis longus and the extensor digitorum longus These muscles are drained by the anterior tibial veins the lateral compartment containing the peroneus longus and brevis muscles which are drained by the peroneal veins Finally the posterior compartment which lodges the tibialis posterior flexor digitorum longus flexor hallucis longus and the soleus muscles is drained by the posterior tibial veins These compartments are invested by very strong sheaths of the fascia cruris (Fig 1)

The gastrocnemius muscle is placed behind the soleus in a separate fascial sheath less well developed than those enveloping the other muscles of the leg The gastrocnemial bellies are drained by a separate pair of veins which join the popliteal vein above the confluence formed by the veins from the other three compartments

In the upright position the vis a tergo is not sufficient to push the blood upwards fast enough to keep the venous outflow equal to the arterial inflow The additional forces necessary are supplied by the action of the surrounding tissues upon veins with competent valves

The surrounding tissues may act upon the veins in two principal ways

At rest a passive support will restrict the inherent tendency of the veins to dilate under pressure The passive support offered by the tissues is equal to the tissue tension which varies from tissue to tissue and at different levels of the same organ (Chapter 4) Other things equal a widening of the diameter of the total venous bed would cause a slowing down of the proximal flow while a constriction would have the opposite effect Even at complete rest the veins of the lower leg are supported by a positive pressure from without and the strength of this pressure is determined by the tonus of the surrounding tissue

During muscular activity the pressure on the veins increases enormously (Chapter 4) Under normal conditions the pressure increases and decreases rhythmically During contraction the blood in the segment of vein under increased pressure will be displaced and the presence of competent valves makes only the proximal route possible

The relations of the veins of the lower extremity change very much Bones tendons fasciae muscles and fatty tissue have different tissue tension and consequently the character of the passive support may vary considerably at different levels Muscular activity may act very forcibly at places where a close contact is established between muscle and vein and may be entirely absent a few inches away where the vein may be related to bone or fat

The author has been unable to find any references in the literature dealing with the influence of different environment upon the venous flow in the lower extremity and no hints of a possible difference of function between different segments of the deep venous trunks A perusal of four major textboks of physiology has given a uniform impression of the conception of the structure of the musculo venous pump mechanism which may be illustrated as done in *Fig 2*

The deep crural veins and the popliteal vein show a striking difference in muscular and fascial relations While the tibial and peroneal veins lie deeply embedded among strong muscles ensheathed by the septa of the crural fascia (Fig 1) the popliteal vein looses its close relation to muscles and fascia as soon as it emerges from the soleus Until it reaches the lower exit of the adductor canal it lies surrounded

by loose fatty tissue behind the popliteal plane of the femur *(Fig 3)* Of the strong fascial planes so prominent in the leg only a fine layer of connective tissue remains in the poples easily torn by the dissecting finger during operation

Thus for a distance of 6—10 cms no muscular force is found working directly upon the vein wall

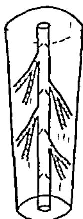


Fig 9 A conception of the structure of the musculo venous pump in the lower extremity based upon the description prevalent in modern text books of physiology Variations in musculo-venous relations are not considered (Compare Fig 26)

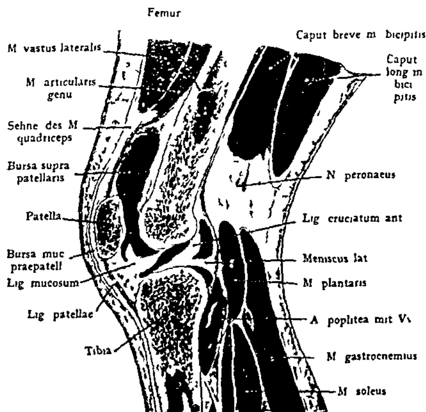


Fig 3 (From Corning Lehrb top Anatomie) Sagittal view of the knee and the popliteal region

CHAPTER III
THE VALVES OF THE DEEP VEINS

The distribution of valves in the deep veins of the lower extremity presents another important difference between the crural and the popliteal (and femoral) segments This subject has been studied in recent years by *Eger & Caspar* (1943) *Powell & Lynn* (1951) *Basmajian* (1952) and *Cockett* (1953)

While the deep crural veins show an abundance of closely spaced valves the valves in the large trunks of the poples and thigh are much

fewer The actual number of valves may vary considerably but never attain the number found in equal segments of intramuscular veins

The following analysis of the distribution of valves in the popliteal femoral and external iliac veins is taken from *Cockett* (1953) *(Fig 4)*

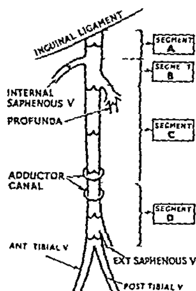


Fig 4 (From Dodd and Cockett Pathology and Surgery of the veins of the lower Limb) Compare analysis in text

Segment A Sixteen out of twenty two cases had one valve in this segment the rest were valveless

Segment B All cases valveless

Segment C Eight cases had four or more valves
Twelve cases had three valves
Three cases had two valves
One case had one valve

Segment D Four cases had three or more valves
Eight cases had two valves
Eleven cases had one valve

The greatest number of valves seen in the entire length was nine the average number was five In one case only two valves were present in the whole vein from the inguinal ligament to the popliteal fossa The most constant valve was that below the point where the profunda femoris vein joins the superficial femoral vein to become the common femoral vein

That a complete congenital absence of valves in the entire deep system may occasionally occur was shown by *Lodin, Lindvall & Gentele* (1961) and *Lindvall & Lodin* (1961) These findings were based on phlebographic examinations

The profunda femoris vein shows closely spaced valves is intermuscular in its relations and emerges into a sparsely valved collecting vein the femoral Thus in these respects it is closely similar to the deep crural veins

It is an often mentioned fact that intramuscular veins — with the possible exception of the soleus sinuses (*Dodd & Cockett* 1956) — are closely valved and that the number of valves decreases sharply as soon as the intimate relation to muscle is lost This is true in the upper as well as in the lower extremity and is found in animals as well as in man

In this connection the findings by *Williams* (1954) who dissected the fore limbs and hind limbs of cats dogs and monkeys are interesting The monkey (resus macaque) not infrequently adopts the upright position and thus the conditions for the venous return in the lower leg may in these periods be considered similar to those met with in man

Williams found that valves were much less common in the hind limb of the monkey than in the dog and cat In all three species valves were about equally distributed in fore and hind limbs This was a reasonable expectation in the dog and cat but if the valves are to be considered an antigravity mechanism they might be expected to be more numerous in the hind limb of the monkey than in the fore limb

Williams is led to support *Jäger s* (1936) theory that the function of the valves is to protect the capillaries and venules from sudden excessive rises of blood pressure during muscular exercise"

At this point we may conclude from Chapter II and III, that the anatomic relations of the deep crural and the popliteal veins are fundamentally different, and that the valvular equipment in these segments show marked quantitative differences

CHAPTER IV
SUBCUTANEOUS AND INTRAMUSCULAR TISSUE TENSIONS

The cells and the intercellular structures are surrounded by the interstitial extracellular fluid which may be imagined as an anastomosing network of very fine channels The hydrostatic tension of the interstitial fluid can be measured by means of simple manometric methods In the literature several investigations are recorded in which the tissue tensions have been estimated by indirect methods The results of these investigations vary rather widely I have preferred only to report the outcome of experiments in which direct measurements have been performed

The concept of the interstitial spaces as a continuous anastomosing network of minute channels admits the possibility of pressure gradients in this system *Burch & Sodeman* (1937) define the tissue pressure as the pressure with which the tissue structures resist any changes in their anatomical relations

a) The subcutaneous tissue pressure

The first to perform direct measurements of the tissue tensions was *Landerer* (1884) He found a subcutaneous pressure in animals (rabbits and dogs) varying between 25 and 65 mm H_2O Only one experiment was performed on man The subcutaneous pressure in the thigh measured in the upright sitting position was found to be 550 mm H_2O

Landerer found that the subcutaneous tissue pressure in rabbits and dogs varied proportionally with the arterial blood pressure This correlation has not been investigated by later authors The highest tissue pressure measured by Landerer (700 mm H_2O) was found in the Achilles tendon of a rabbit

Meyer & Holland (1932) determined the intracutaneous and subcutaneous tissue tension in normal subjects by means of a direct manometrical method using a fine cannula connected to a manometer They found the intracutaneous pressure to fluctuate about a mean

value of 70 mm H_2O The intracutaneous tension was found to be unrelated to the distance from the heart and it was not affected by changes in capillary pressure

The same authors found a mean value of subcutaneous pressure on the fore arm of 30 mm H_2O (40—20 mm H_2O) This tension was not affected by changes in capillary pressure or by variations in the distance from the heart level

Burch & Sodeman (1937 a 1937 b) using a similar method found slight variations in the subcutaneous pressure at heart level in different regions Thus in normal individuals the mean value at the dorsum of the hand was 17 9 mm H_2O in the pretibial area 37 1 mm H_2O In the standing position the subcutaneous pressure at the dorsum of the foot increased from a mean value of 30 8 mm H_2O to 80 5 mm H_2O

The same authors determined the subcutaneous pressure in the pretibial area in patients with congestive heart failure during the period *when oedema was increasing The pressure varied between 58 and 267* mm H_2O compared to a normal mean value of 37 1 mm H_2O

Burch & Sodeman (1937) agree with *Meyer & Holland* (1932) that increase in venous blood pressure over short intervals of time has only a very slight effect on the subcutaneous tissue pressure *Holland & Meyer* (1932) found however an unaltered subcutaneous pressure in patients with cardiac oedema compared with normal values They do not state whether the oedema was increasing during the time of investigation

Wells Youmans & Miller (1938) measured the subcutaneous pressure in normal subjects at rest and in the upright position as well as in patients with slight oedema and in arms and legs of normal individuals following prolonged venous congestion produced by inflation of a blood pressure cuff to pressures from 50 to 100 cms H_2O and found that nearly half the values ranged from 20 to 60 mm H_2O (Fig 5) The *subcutaneous pressure was found to rise somewhat but not much and* not regularly after prolonged congestion (Fig 5) The rise was usually not more than 10 to 30 mm H_2O Values of 110 or 150 mm H_2O were exceptional and were measured in the subcutis of the lower leg after nearly three hours of quiet standing

Thus the various authors agree that the pressure in the subcutis ranges between 10 and 70 mm H_2O in normal subjects There are indications that prolonged venous congestion may raise the pressure moderately and that distension of the subcutis by a developing oedema may have the same effect It seems as if the subcutaneous pressure in

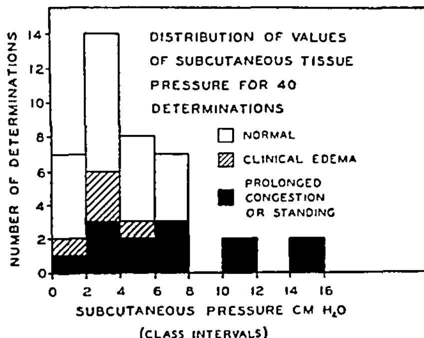


Fig 5 Histogram showing distribution of values of subcutaneous pressure (From Wells Youmans and Miller 1938)

normal individuals is independent of the venous pressure within wide limits

It would be interesting to compare the subcutaneous pressure in normal subjects and in patients with chronic venous insufficiency The indurative changes which are seen in the severe forms of venous disturbances would probably affect the tension in the subcutis Such measurements have not been published as yet

b) The intramuscular tissue pressure

Henderson Oughterson Greenberg & Searle (1935) made some interesting studies of the intramuscular pressure in the relaxed biceps brachii in normal individuals and in patients confined to bed They used a direct manometrical method very much like all the other authors mentioned in this chapter In healthy young men the average value was 74 mm H O while the average value in patients in bed was found to be 47 mm H O A significant decrease in intramuscular pressure was found to take place after operation especially after major

abdominal surgery performed under general anaesthesia Thus the intramuscular pressure measured twelve hours before operation averaged 73 mm H_2O while the average value after operation was 48 mm H_2O

Increase in intramuscular tension in the relaxed biceps brachii was found after administration of strychnine sulfate and after inhalation of CO

The same authors determined the pressure in the gastrocnemius muscle in one patient standing at rest to 143 mm H_2O Maximal contraction of the gastrocnemius (standing on one toe) increased the pressue to 312 mm H_2O

Wells, Youmans & Miller (1937) showed in a series of experiments that in the normal relaxed subject in the recumbent posture the intramuscular pressure values varied in different individuals and in the same person on different days from 20 to 110 mm H_2O Values below 50 mm H_2O were found in most studies on muscles such as the biceps brachii and the gastrocnemius which have a thin or loose fascial covering The higher values usually from 50 to 100 mm H_2O were found in measurements on the anterior tibial and soleus which are invested by a tight fascial sheath

The same authors found that intramuscular pressure responded immediately to changes in venous pressure in the soleus and anterior tibial muscles while the pressure changes in the gastrocnemius were minimal

The authors conclude that intramuscular pressure in the relaxed subject *appears to be determined by a variety of factors of which the* most important are the tightness of the overlying fascia the amount of extravascular fluid present in the muscle and the degree of filling of its blood vessels

The maximal values of intramuscular pressure during voluntary contractions were measured by the same authors Here again the muscles with a tight fascial covering showed values of contraction pressure which were much higher than those found in muscles with a poorly developed fascia (Fig 6) It is of interest to note that the highest values were obtained from the soleus and anterior tibial muscles which form part of the section of the venous pump with which this paper is concerned and that the highest values were obtained in the region where the middle perforating veins join the posterior tibial veins

Measurement of intramuscular pressure have only been performed on normal subject It would be interesting to see if patients with

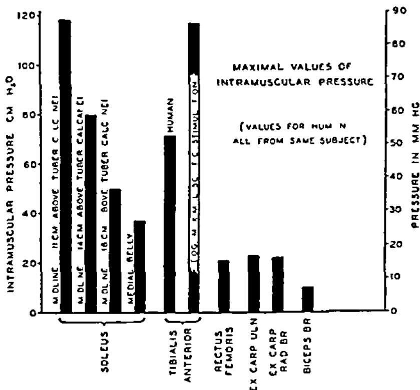


Fig 6 Maximal values of intramuscular pressure during voluntary contractions in man and during maximal sciatic stimulation in the dog (From Wells Youmans and Miller 1938)

chronic venous insufficiency show changes in intramuscular pressure at rest and during maximal muscular contraction This is especially true in the deep venous incompetence of the phlebographic Group III (Chapter XI) As it is we do not know for certain whether the phlebosclerotic changes in the veins affect the pressure inside the fascial compartment or if changes in muscular pressure occur which might have a deleterious effect on the venous pump

A comparison between the subcutaneous and intramuscular pressures in the lower leg in normal subjects shows, that while the subcutaneous pressure at rest ranges between 10 and 70 mm H_2O the intramuscular pressure is always somewhat higher, from 50 to 110 mm H_2O in the muscles belonging to the section of the venous pump with which we are concerned

The intramuscular pressure was found to rise with the venous pressure, while the subcutaneous pressure was only slightly affected by changes in pressure in the adjacent veins.

Finally, contraction of the muscles of the section of the venous pump under discussion raises the intramuscular pressure to levels many times higher than the highest values obtained from the subcutis.

CHAPTER V

VENOUS PRESSURE MEASUREMENTS

Investigations on the pressure in the veins of the lower extremity at rest and under dynamic conditions have been of the greatest value for our understanding of venous physiology and pathophysiology. It is not the intention here to review the extensive literature on venous pressure measurements, but only to refer to the results of these investigations in so far as they seem pertinent to the present study. At present most authors are in agreement as regards the changes in *venous pressure during rest and activity,* and the present author has chosen the works of *Højensgard & Sturup* (1949, 1952) and *Sturup & Højensgard* (1950 a, 1950 b) as the basis for the following summary. Both as regards technique and critical evaluation of the results the work of these authors is as yet unsurpassed.

It will be practical to consider the venous pressure measurements in the various parts of the venous systems of the lower extremity separately (saphenous veins, deep veins of the thigh, deep crural veins and ankle perforating veins) and to report the findings (or lack of investigations) in normal subjects and in patients with chronic venous insufficiency in each venous system.

A. *Subcutaneous veins (saphenous system)*

1) *Normal subjects.* Normal subjects in the motionless standing position show a pressure in the saphenous veins which at each point is equal to the hydrostatic pressure of a column of blood reaching to the level of the heart.

Muscular work (walking) causes the pressure in the veins to fall gradually until it reaches a stable level which in the lower leg is 600—900 mm H_2O below the pressure found in the motionless standing position

2) *Patients with idiopathic varicose veins* In the motionless standing position the pressure in the varicose saphenous veins is at all levels equal to the hydrostatic pressure of a column of blood reaching to the level of the heart During walking there is none or only a negligible fall in the mean pressure in the varicose veins A fall in pressure occurs gradually when the incompetent saphenous vein is compressed above the point of measurement This is observed clinically as emptying of the veins in the Perthe s test

3) *Patients with total postthrombotic destruction of the valves in the deep veins of the lower extremity and varicose superficial veins*

In the motionless standing position the pressure in the subcutaneous veins is — at all levels — equal to the hydrostatic pressure of a column of blood reaching to the level of the heart Walking fails to produce a decrease in pressure in the saphenous veins

Compression of the incompetent saphenous veins by a tourniquet does not effect a fall in pressure Clinically this is demonstrated as "no emptying of the veins in the Perthe s test

4) *Patients with partial postthrombotic destruction of the deep veins*

In some patients in whom the thrombotic process had left a few deep veins intact a demonstrable decrease in pressure could be observed during walking with tourniquet (Postthrombotic *B Højensgard & Sturup* (1949)

B The deep veins of the thigh

Højensgard & Sturup (1952) made the very interesting observation that the pressure in the popliteal vein (the tip of the catheter was placed in the upper popliteal or lower femoral vein) during the motionless standing position was equal to the calculated hydrostatic pressure of a column of blood reaching to the heart and that walking produced no decrease in mean pressure the pressure fluctuated about the hydrostatic pressure at rest with very modest excursions *These findings were identical in normal subjects and in all forms of venous insufficiency*

C The deep veins of the leg

The pressure in the deep crural veins has never been measured

viously) is asked to tramp the pedal as far down as possible This very powerful contraction is repeated three times (the three contractions being timed to last fifteen seconds) and the second film is exposed immediately after the end of the third contraction as soon as the leg has returned to the resting position

The patient is then returned to the horizontal position with the needle *in situ* while the films are being developed Only antero — posterior exposures are generally necessary as the subcutaneous veins very rarely disturb the picture of the deep veins and the ankle perforating veins

B Phlebographic demonstration of the function of the venous pump

The intention when using a dynamic type of phlebography is to get an idea of the function of the venous pump In order to obtain comparable results the apparatus must be calibrated by means of a normal material The lowest number of tramps needed to empty the normal veins is chosen as standard procedure

Fourteen normal subjects were examined as a control material In these phlebograms most or all of the contrast medium had disappeared from the veins of the leg and lower thigh in the second exposure that is from the musculo fascial compartments of the leg and their corresponding collecting vein the vena poplitea This was taken as a phlebographic demonstration of a normal function of the musculo venous pump in the leg

On the other hand it was found that in a great many phlebograms from patients with various forms of chronic venous insufficiency the second exposure showed a marked retention of contrast medium in the deep veins of the leg This was regarded as a phlebographic demonstration of an impaired function of the musculo venous pump mechanism in the leg

C Material

The material on which the following chapters are based consists of 337 phlebograms from patients with chronic venous insufficiency Apart from the first period when the method was tried out only pa

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Fig 7 Patient in the horizontal position prior to phlebografic examination
Fig 8 The table has been tilted into an angle of 45 degrees from the horizontal plane The extremity to be examined rests on a spring pedal to which a considerable weight is attached (12 kgs)

tients with the more severe forms of venous insufficiency were examined (41 per cent of the extremities in the material were ulcerated). The figures and percentages presented in the following chapters are therefore not representative as regards chronic venous insufficiency as a whole but only of the present material.

The number of patients in the phlebographic groups and the ratio men/women are recorded in Table I.

TABLE I

Records the number of phlebograms in the different phlebographic groups and the ratio men/women

	Men	Women	Total	Women %
Group I type A	13	36	49	74
Group I type B	3	9	12	75
Group II type A	31	108	139	78
Group II type B	19	43	62	69
Group III	13	63	76	83

D The phlebographic groups

An analysis of the phlebograms from extremities with chronic venous insufficiency showed that the phlebographic material could be divided into five characteristic groups (Arnoldi 1961 a).

In the phlebographical analysis a set of criteria were employed encompassing functional as well as morphological characteristics.

First, the phlebograms were divided into two main divisions: those with a normal function of the venous pump (good emptying in the second exposure) and those where the venous pump was impaired (retention of contrast in the second exposure). In the first division (*normal function of the venous pump Group I*) the contrast filled deep veins appeared normal in the vast majority of the phlebograms and the valves in the communicating veins seemed to be competent. These patients had varicose saphenous veins. The division contained, however, a small number of phlebograms with signs of a previous attack of deep thrombophlebitis *confirmed by the patients' history*. *It was therefore* found necessary to divide Group I into two types A and B. Group I type A (Fig. 14) contains the patients with primary saphenous varicosities of the simple type, while Group I type B contains patients with postthrombotic changes in the deep veins with normal function of the venous pump. Superficial varicosities were always present.

In the second division of the material (impaired or destroyed func

tion of the venous pump) the presence of large incompetent ankle perforating veins was a dominant characteristic in a large number of cases and this characteristic was employed to distinguish between Group II (incompetent ankle perforating veins) and Group III (impaired function of the venous pump but competent ankle perforating veins)

In Group II it was possible to distinguish between two subgroups according to the degree of impairment of the venous pump

In Group II type A (Fig 16 17 18) the venous pump was deficient owing to a leak through the incompetent ankle perforators Some degree of function remained however as the contrast medium was seen — in the second exposure — to have been sucked back from the subcutaneous system into and upwards through the deep veins

In Group II type B (Fig 20 21 22) the venous pump was completely destroyed and the contrast mixed blood was seen to move slowly upwards through the superficial as well as the deep veins with a speed corresponding to the pressure exerted by the vis a tergo quite unaffected by muscular activity (serial phlebography)

Group II type A contained patients with normal deep veins as well as patients with deep crural veins showing signs of an earlier attack of deep thrombophlebitis

Group II type B only contained extremities with postthrombotic valvular destruction of all the deep veins in the phlebogram

A further analysis of the material (Arnoldi (1961 b) showed that phlebographically normal popliteal valves were found in the large majority of the postthrombotic extremities in Group II type A while the large majority of the patients in Group II type B had no visible popliteal valves (Table II)

TABLE II

A comparison between the postthrombotic cases in Group II type A and Group II type B The state of the popliteal valves the type of anticoagulants given during the acute thrombotic attack and the severity of the chronic stage are recorded

	Group II type A	Group II typ B
Number of cases	27 (100 0 %)	62 (100 0 %)
Popliteal valves normal	22 (81 5 %)	1 (1 7 %)
Popl valv not present	2 (7 4 %)	53 (85 4 %)
Popl valv not visible	3 (11 1 %)	8 (12 9 %)
Heparin treatment during acute attack	18 (66 7 %)	5 (8 0 %)
Dicoumarol alone during acute attack		10 (16 0 %)
Embolus in connection with acute attack		[illegible] 11 2
Number of leg ulcers	14 (52 %)	[illegible]

Fig 14 Phlebogram from patient with primary varicose veins (Group I type A)
Fig 14 a shows the location of contrast medium immediately after injection in the quiet standing position (Diastole II) The contrast filled deep crural and popliteal veins have normal contour and valves Traces of contrast medium outside the fascia cruris
Fig 14 b Exposed immediately after cessation of third muscular contraction (Diastole I) The deep crural and popliteal veins are empty apart from slight traces of contrast medium at the valvular pocketts Normal function of the venous pump
Fig 16 Phlebogram from patient with varicose veins incompetent ankle perforating veins and intact popliteal valves
(Group II type A)
Fig 16 a shows the location of contrast medium immediately after injection in the quiet standing position (Diastole II) The contrast is seen in the deep crural veins in the lower two thirds of the leg Some contrast has been shunted out through two incompetent medial ankle perforators and has filled a section of the subcutaneous system
Fig 16 b is exposed immediately after the end of third muscular contraction (Diastole I) As a result of muscular activity the contrast medium has moved upwards *in the deep veins The popliteal vein is now visible and is seen to have normal* valves as have the visible deep crural veins The lower fourth of the leg is free from contrast The contrast medium in the incompetent ankle perforating veins and subcutaneous veins has been sucked back into the deep system
Fig 17 Phlebogram from patient with varicose veins incompetent ankle perforating veins and intact popliteal valves (Group II type A)
Fig 17 a shows the location of contrast medium during Diastole II Contrast has been shunted out through an incompetent medial ankle perforator and a short segment of subcutaneous vein has become visible
Fig 17 b exposed during Diastole I As the result of muscular activity the lower part of the deep crural veins are by now empty The contrast has been sucked back into the deep veins from the subcutaneous and ankle perforating veins and the column of contrast has reached the popliteal vein
Fig 18 Phlebogram from patient with varicose veins incompetent ankle perforating veins earlier attack of deep thrombophlebitis but intact popliteal valves (Group II type A)
Fig 18 a Diastole II The contrast medium is seen in the lower part of the deep crural veins some of which have normal valves and contours Some contrast medium has been shunted into the subcutaneous system by way of an incompetent lateral ankle perforator A section of the subcutaneous system has become visible
Fig 18 b Diastole I The contrast has disappeared from the lower fourth of the deep veins and from the ankle perforator and subcutaneous veins The proximal parts of the deep veins and the popliteal vein have become visible Some deep veins show a woolly irregular contour and in sections the deep valves seem to have been destroyed The popliteal valves are intact

Fig. 14



Fig. 1?





Fig. 17



Fig. 18

Fig 15 Phlebogram from patient with primary varicose veins (Group I type A)
Fig 15 a shows the location of contrast medium immediately after injection in the quiet standing position (Diastole II) The contrast filled deep crural and popliteal veins have normal contour and valves Traces of contrast medium outside the fascia cruris
Fig 15 b Exposed immediately after cessation of third muscular contraction (Diastole I) The deep crural and popliteal veins are empty apart from slight traces of contrast medium at the valvular pocketts Normal function of the venous pump
Fig 16 Phlebogram from patient with varicose veins incompetent ankle perforating veins and intact popliteal valves
(Group II type A)
Fig 16 a shows the location of contrast medium immediately after injection in the quiet standing position (Diastole II) The contrast is seen in the deep crural veins in the lower two thirds of the leg Some contrast has been shunted out through two incompetent medial ankle perforators and has filled a section of the subcutaneous system
Fig 16 b is exposed immediately after the end of third muscular contraction (Diastole I) As a result of muscular activity the contrast medium has moved upwards in the deep veins The popliteal vein is now visible and is seen to have normal valves as have the visible deep crural veins The lower fourth of the leg is free from contrast The contrast medium in the incompetent ankle perforating veins and subcutaneous veins has been sucked back into the deep system
Fig 17 Phlebogram from patient with varicose veins incompetent ankle perforating veins and intact popliteal valves (Group II type A)
Fig 17 a shows the location of contrast medium during Diastole II Contrast has been shunted out through an incompetent medial ankle perforator and a short segment of subcutaneous vein has become visible
Fig 17 b exposed during Diastole I As the result of muscular activity the lower part of the deep crural veins are by now empty The contrast has been sucked back into the deep veins from the subcutaneous and ankle perforating veins and the column of contrast has reached the popliteal vein
Fig 18 Phlebogram from patient with varicose veins incompetent ankle perforating veins earlier attack of deep thrombophlebitis but intact popliteal valves (Group II type A)
Fig 18 a Diastole II The contrast medium is seen in the lower part of the deep crural veins some of which have normal valves and contours Some contrast medium has been shunted into the subcutaneous system by way of an incompetent lateral ankle perforator A section of the subcutaneous system has become visible
Fig 18 b Diastole I The contrast has disappeared from the lower fourth of the deep veins and from the ankle perforator and subcutaneous veins The proximal parts of the deep veins and the popliteal vein have become visible Some deep veins show a wall irregular contour and in sections the deep valves seem to have been destroyed The popliteal valves are intact

Fig 15



Fig 16





Fig 17



Fig 18



Fig 20 Phlebogram from patient with varicose veins incompetent communicating veins and previous deep thrombophlebitis which has involved the popliteal vein (Group II type B)
Fig 20 a Diastole II Immediately after injection in the quiet standing position the contrast medium has filled the distal two thirds of the deep crural veins Some contrast has been shunted out into the subcutaneous system via incompetent lateral and medial ankle perforating veins
Fig 20 b Diastole I Immediately after the end of muscular activity contrast is seen in the deep crural veins from the ankle up till the popliteal level The deep veins are irregular somewhat woolly in contour A few valves are seen in the anterior tibial veins but the rest of the deep system is irregular and valveless including the popliteal vein

The contrast remains in the communicating veins and has progressed further upwards in the subcutaneous veins Contrast is still seen in the lower fourth of the leg (Compare Figg 16 17 and 18)

There remained a group of patients whose phlebograms showed an impaired or completely destroyed function of the venous pump but where the ankle perforating veins were competent and the valves of the deep veins apparently normal In the large majority of these patients (Group III proper Fig 24 25) the diameter of one or several of the deep crural veins was abnormally wide (When grouping the phlebograms the author used the width of the fibula measured ten cms below

Fig 21 Fig 22



Fig 21 Phlebogram from patient with varicose veins incompetent communicating veins and wide pread postthrombotic valvular destruction including the popliteal vein (Group II type B)

Fig 21 a Diastole II The contrast medium i located in the severely deranged deep veins without demonstrable valve Contrast has reached the subcutaneous veins by way of three medial and two lateral incompetent communicating veins

Fig 21 b Diastole I Muscular activity has failed to empty any section of the deep system The contrast has not been sucked back from the subcutaneous veins instead a further filling has taken place

Fig 22 Phlebogram from patient with varicose veins incompetent communicating veins and widespread postthrombotic valvular destruction including the popliteal vein (Group II type B)

Fig 22 a Diastole II The contrast medium is seen in irregular valveless deep channels as far as the popliteal vein The subcutaneous system has received contrast via four medial and two—three lateral incompetent perforating veins

Fig 22 b Diastole I No emptying after muscular activity Further filling of the superficial veins

the tip of the capitulum for comparison) The phlebograms of Group III proper all showed a diameter equal to or wider than the fibula at this level A small number of phlebograms were referred to as Group IV In these cases the diameter fell short of the diameter of the fibula but otherwise the characteristics were identical with those of Group III

CHAPTER VII
THE VENOUS RETURN FROM THE LOWER LEG
IN THE NORMAL EXTREMITY

The section of the lower extremity with which we are concerned at present may be represented by the schematic drawing shown as Fig 9. The deep crural veins with their abundancy of valves are closely surrounded by muscles which are ensheathed by the septa of the fascia cruris while the collecting popliteal vein — much poorer in valves — is represented as being entirely free of muscular relations. The ankle perforating veins and the subcutaneous venous system are represented schematically.

In the following paragraphs the author intends to describe the function of the venous pump in the normal extremity using the information obtained from the literature regarding tissue tension and venous pressure (Chapter IV and V) in combination with the findings which emerged from the analysis of the phlebographic material.

Diastole II Systole and Diastole I

In order to facilitate the evaluation of the venous return the author distinguishes between three phases in the cyclus contraction/relaxation of the muscles of the pump sections namely Diastole II Systole and Diastole I.

The first exposure in the standardized dynamic method of phlebography was made at a time when the extremity to be examined had been completely at rest for several minutes. The extremity was not weight bearing. Serial phlebography has shown that the blood flow during rest is slow (about 1 - 2 cms per seconds) and that this rate of flow is the same in normal legs and in extremities with chronic venous insufficiency that is whether the valves in the deep veins are functioning or not. Although direct measurements of the pressure in the deep crural veins have not been performed it may be assumed that the pressure in the deep veins at rest at any point is equal to the hydrostatic

pressure of a column of blood reaching to the level of the heart and that the valves are open

This period of slow steady flow is called *Diastole II*

Systole The period from the onset of muscular contraction until relaxation sets in is called systole

Diastole I At cessation of muscular contraction the musculo fascial compartment contains less blood than when the contraction began The sudden fall in muscular tension (1200 to 50 mm H O in the lower third of the soleus) and the diminished contents of the musculo fascial compartment is in the following assumed to cause a fall in venous pressure in the deep crural veins below that found in the collecting (popliteal) vein outside the section of the muscle pump

The inflow from the arterial system and from the veins outside the musculo fascial compartment will fill the veins of the pump section Diastole I is the phase which begins at the cessation of muscular contraction and lasts until the pressure in the deep crural veins has risen above the pressure in the popliteal vein When this happens the popliteal valves must open and the state of slow steady flow is re established (Diastole II)

The second exposure in the standardized method of dynamic phlebography is made immediately after the leg has returned to the resting

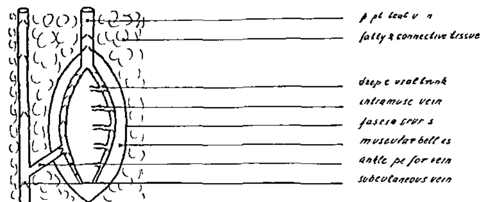


Fig 9 Schematic drawing of a musculo venous pump section in the lower leg The deep crural veins with their abundancy of valves are closely surrounded by muscles which are sheathed by the strong crural fascia The collecting popliteal vein is shown in its relation to the loose fat in the popliteal space A superficial vein is connected with the deep veins through an ankle perforating vein

CHAPTER VII
THE VENOUS RETURN FROM THE LOWER LEG IN THE NORMAL EXTREMITY

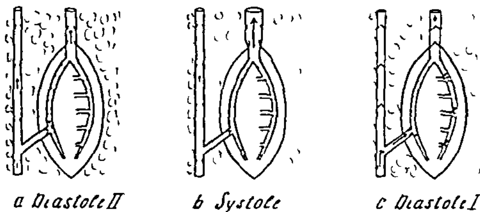
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Figg 10 a b and c represent in schematic form the function of the venous pump in the lower leg during Diastole II Systole and Diastole I in a normal subject

Fig 10 a Diastole II This is the state of slow steady flow maintained b the vis a tergo The valves in the subcutaneous deep crural and popliteal vein are open allowing the hydrostatic forces full effect The difference in environmental support raises the effective pressure in the deep crural veins to a slightly higher level than in the subcutaneous veins Hence the closed valves in the communicating vein

Fig 10 b Systole As the result of muscular contraction the pressure in the deep crural veins rises above that in the popliteal vein and the blood is pres ed out of the musculo fascial compartment Normal valves prevent an outflow distally and through the communicating veins

Fig 10 c Diastole I At the cessation of Systole the pressure in the deep crural veins falls abruptly When the pressure falls below the popliteal values the popliteal valves will close and seal the upper outlet from the pump section

The low pressure inside the fascia cruris makes a central flow possible from the subcutaneous into the deep system via the communicating veins The pressure in the adjacent segment of the subcutaneous veins will begin to fall

The low pressure in the deep trunks will facilitate the outflow from the muscular tributaries

Filling of the central trunks from the muscular tributaries and from the superficial veins cau es a rise in pressure eventually inverting the pressure gradient at the popliteal valves When this has been effected the popliteal valves will open and the state of steady flow (Diastole II) has become reestablished The cycle is complete

answered but the pressure absorbing qualities of the spongiosa and the slow proximal progress of the contrast make it improbable that this factor is of any great importance Until further investigation proves different we will assume that the difference in deep and subcutaneous pressure is real

Another factor which may go a long way in explaining the difference in pressure in the deep and subcutaneous veins is the pressure in the surrounding tissues The tissue pressure in the subcutis (10—70 mm H_2O) was found to be somewhat lower than the intramuscular pressure at rest (50—110 mm H_2O) The difference is probably even more pronounced as complete relaxation is well nigh impossible to achieve in a standing conscious person Assuming that the elastic properties of the vein wall are equal in the deep and superficial veins the difference in tissue support would tend to diminish the effective pressure in the subcutaneous veins compared with the deep veins

B Systole

In the normal extremity muscular exercise causes the pressure in the great saphenous vein — measured at the ankle — to fall from *about 1000—1200 mm H_2O to about 300—400 mm H_2O This fall in* pressure is gradual and is within certain limits dependent upon the muscular work involved The pressure in the popliteal vein fluctuates about a mean value of 400—600 mm H_2O that is muscular exercise leaves the mean pressure in this vein practically unaltered and the result at knee level is that the pressure in the saphenous system eventually falls below that in the politeal vein

The pressure inside the fascia cruris has not been measured and the pressure in the ankle perforating veins during muscular contraction is also unknown

Muscular contraction caused a steep rise in pressure in the muscles of the leg highest in the soleus (1200—480 mm H_2O) and the tibialis anterior (700 mm H_2O) while the gastrocnemius only showed a maximal contraction pressure of 310 mm H_2O

Barcroft & Dornhorst (1948) demonstrated by means of plethysmographic investigations that the pump out mechanism of the leg in a normal person could overcome a constricting force of 1200 mm H_2O

Thus although direct measurements of the venous pressure in the deep crural veins are still missing we may assume from the circumstantial evidence at hand that the pressure of the surrounding contracting muscles raises the venous pressure high enough to overcome

the hydrostatic pressure at the outlet of the musculo fascial compartments by a comfortable margin

The muscular contraction raises the pressure in the deep veins of the leg far above the subcutaneous venous pressure As a consequence the valves at the juncture of the communicating veins and the deep veins must remain closed during systole

The pressure in the popliteal vein also rises during muscular contraction but the rise is modest This fact is more easily understood when one realises that no appreciable muscular action is brought to bear upon the popliteal vein and that the loose fatty tissue embedding the vein may act as a buffer by allowing the vein to expand

All investigations show that the fall in pressure in the subcutaneous veins during exercise is gradual and that a single contraction only results in a moderate fall in mean pressure

The present method of dynamic intraosseous phlebography does not show the expulsion of the contrast mixed blood during systole but only what has happened to the contrast after three cycles of contraction and relaxation

C Diastole I

The pressure in the great saphenous vein at ankle level falls gradually during rhythmic muscular contractions from a level corresponding to the hydrostatic pressure of a column of blood reaching to the right auricle to a minimum level of about 300—400 mm H O This fall in pressure is due to two factors namely the presence of competent valves in the subcutaneous veins and the central flow of blood through the communicating veins into the deep veins

We have seen that the phlebographic investigations by means of the dynamic intraosseous method make it highly improbable that a central flow through the communicating veins takes place during the phase of prolonged quiet standing (Diastole II) and that the steep rise in intramuscular pressure during Systole makes such a flow even less feasible in this phase

We know however from clinical experience and from the Perthes test that a series of rhythmic muscular contractions will empty the subcutaneous veins by means of an inflow of blood through the communicating veins into the deep crural veins To understand how this inflow is made possible the hydromechanics in the leg in the period following immediately after the cessation of muscular contraction are of special interest

When relaxation sets in the very high intramuscular tension which was found during Systole falls To what levels it will fall is still unknown as the measurements available only tell us about the tension in the relaxed muscle after prolonged rest that is in Diastole II This resting value was found to range from 20—50 mm H O in the gastrocnemius and from 50—110 mm H_2O in the soleus and tibialis anterior The intramuscular tissue tension varies with the tension in the adjacent veins As the veins in the pump section contain less blood at the end of Systole than after a period of rest it is not inconceivable that a lower muscular tension exists in Diastole I than in Diastole II

If we assume that the venous pressure in the by now partially empty deep crural veins falls to somewhere near the level of the resting intramuscular pressure a very considerable difference in pressure will suddenly exist between the superficial veins (1200—600 mm H_2O) and the deep crual veins (110—20 mm H_2O) Now for the first time in the entire cyclus contraction/relaxation a central flow of blood through the communicating veins is made possible The pressure in the subcutaneous veins will begin to fall

Diastole I the period during which this central flow is possible is probably of short duration The fall in pressure in the subcutaneous veins is gradual and the minimal values are not reached until a number of muscular contractions have been performed This must mean that only a fraction of the blood contained in the crural parts of the subcutaneous venous system reaches the deep crural veins in each Diastole I

The deep trunks receive blood not only from the communicating veins but also from the numerous muscular tributaries The low pressure in the deep trunks in Diastole I facilitates the outflow from the tributaries The inflow from the communicating veins and the increased flow from the subfascial tributaries tend to fill the partially empty deep trunks rapidly and the rigid fascial sheaths have the effect that an increase in volume is followed by a rapid increase in pressure inside the musculo fascial compartment

When the pressure in the deep veins below the popliteal valves rises above that found proximal to the valves (and this pressure has not changed appreciably during the whole cyclus) the valves will open We have come to the end of Diastole I and the phase of slow steady flow has been reached (Diastole II)

Jager (1936) observed directly that relaxation following contraction of the leg muscles in the frog caused the valves in the veins proximal

Fig 11 Fig 12



Fig 11 Phlebogram from normal subject

Fig 11 a shows the location of contrast medium immediately after injection during the quiet standing position (Diastole II) The contrast filled deep crural and popliteal veins have normal valves The subcutaneous veins contain no contrast

Fig 11 b exposed immediately after the end of muscular contraction (Diastole I) Very fine traces of contrast medium left in the upper half of the leg

Fig 12 Phlebogram from normal subject

Fig 12 a shows the location of contrast medium in the deep crural and popliteal veins during Diastole II

Fig 12 b shows good emptying after three muscular contractions (Diastole I) Retention of contrast is seen proximal to the valves This is considered within the normal limits

to the muscle to close for a few moments whereupon the valves opened again and the proximal flow began

Fig 10 a b and c describe the three phases in the contraction/relaxation cyclus in the normal leg

Fig 11 and 12 are examples of phlebograms from a normal leg

When relaxation sets in the very high intramuscular tension which was found during Systole falls. To what levels it will fall is still unknown as the measurements available only tell us about the tension in the relaxed muscle after prolonged rest that is in Diastole II. This resting value was found to range from 20—30 mm H_2O in the gastrocnemius and from 50—110 mm H_2O in the soleus and tibialis anterior. The intramuscular tissue tension varies with the tension in the adjacent veins. As the veins in the pump section contain less blood at the end of Systole than after a period of rest it is not inconceivable that a lower muscular tension exists in Diastole I than in Diastole II.

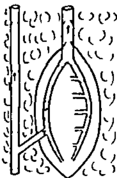
If we assume that the venous pressure in the by now partially empty deep crural veins falls to somewhere near the level of the resting *intramuscular pressure* a *very considerable difference* in pressure *will* suddenly exist between the superficial veins (1200—600 mm H_2O) and the deep crual veins (110—20 mm H_2O). Now for the first time in the entire cyclus contraction/relaxation a central flow of blood through the communicating veins is made possible. The pressure in the subcutaneous veins will begin to fall.

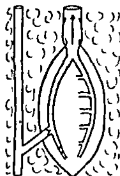
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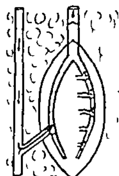
The deep trunks receive blood not only from the communicating veins but also from the numerous muscular tributaries. The low pressure in the deep trunks in Diastole I facilitates the outflow from the tributaries. The inflow from the communicating veins and the increased flow from the subfascial tributaries tend to fill the partially empty deep trunks rapidly and the rigid fascial sheaths have the effect that an increase in volume is followed by a rapid increase in pressure inside the musculo-fascial compartment.

When the pressure in the deep veins below the popliteal valves rises above that found proximal to the valves (and this pressure has not changed appreciably during the whole cyclus) the valves will open. We have come to the end of Diastole I and the phase of slow steady flow has been reached (Diastole II).

Jager (1936) observed directly that relaxation following contraction of the leg muscles in the frog caused the valves in the veins proximal







Figg 13 a b and c represent in schematic form the function of the venous pump in the lower leg during Diastole II Systole and Diastole I in an extremity with primary varicose vein (*Group I type 4*)

Fig 13 a Diastole II During the phase of slow steady flow the valves in the deep crural and popliteal veins are open and the driving force is effected by the vis a tergo The hydrostatic forces are fully effective in the deep as well as in the varicose subcutaneous veins Owing to the slightly higher pressure inside the fascia cruris the valves in the communicating veins are closed during Diastole II

Fig 13 b Systole The rising pressure inside the fascia cruris expels the blood from the musculo fascial compartment The route through the popliteal vein is the only feasible owing to the normal valves in the deep crural and the communicating veins

Fig 13 c Diastole I The sudden fall in pressure inside the fascia cruris below that found in the popliteal vein will close the popliteal valves A central flow through the communicating vein is now possible This has a tendency to lower the pressure in the varicose subcutaneous veins but owing to the lack of functioning valves here a retrograde flow from above will restore the high venous pressure and make up for the loss of blood to the deep veins

motionless semierect position In the phase of steady flow the valves in the deep veins must be open and the hydrostatic pressure must be effective at all levels This has been shown to be the case in the superficial veins and the popliteal vein by direct measurements of pressure

As in the normal leg the pressure in the deep veins may be assumed to be somewhat higher than in the subcutaneous veins at the same level (owing to the difference in tension in the surrounding tissues) Consequently the valves in the communicating veins stay closed in this phase

Diastole II is the phase demonstrated by the first phlebogram At the moment of exposure the contrast medium is confined to the deep trunks *and nothing is seen in the communicating veins or in the* saphenous varicosities

B Systole

Maximal contraction of the soleus *and the interior tibial muscles* causes a steep rise in intramuscular pressure from 50—110 mm H_2O at rest to 700—1200 mm H_2O during contraction The contraction pressure will easily overcome the pressure in the popliteal vein and is higher than the maximal hydrostatic pressure found in the lowest part of the *leg in the semierect position adopted for dynamic phlebography* The sudden steep rise in pressure inside the musculo fascial compartment *will squeeze the blood into the popliteal vein This is the only* way possible owing to the valvular competency and the fact that the pressure in the lower part of the soleus rises to much greater heights than in the upper part (1200 mm H_2O against 480 mm H_2O)

The high pressure in the deep veins makes a central flow through the communicating veins impossible during Systole

The standardized form of dynamic intraosseous phlebography gives *no information as to what happens to the contrast medium during* Systole The second exposure is made after the completion of three cycles in Diastole I

C Diastole I

At the cessation of contraction we assume that the intramuscular tension returns to somewhere near the resting level (50—110 mm H_2O) The pressure in the popliteal vein reaches its minimum but the fall is modest The pressure in the deep veins of the leg falls below that in *the popliteal vein The resulting pressure gradient will cause the popliteal valves to close* This conception is supported by the direct observations by Jäger (1936) on the conditions in the veins of the lower extremity of the frog

The low pressure in the deep crural veins in Diastole I will favour a central flow through the communicating veins from the subcutaneous system where the mean pressure until now has remained practically unchanged The central flow is possible *as long as the pressure in the* saphenous veins is higher than in the deep veins As in normal subjects the low pressure inside the fascia cruris must be supposed to rise

quickly as a result of the inflow from the subcutaneous veins and from the arteries and owing to the rigid character of the fascial sheaths.

The inrush of blood from the saphenous veins into the deep veins will tend to diminish the volume of blood and the pressure in these veins. This tendency to a fall in pressure is compensated by a retrograde flow of blood through the incompetent sapheno-femoral (popliteal) junctions during Diastole I. If this backflow is hindered by means of a tourniquet the flow into the deep veins will empty the superficial varicosities (Perthes test).

Diastole I is phlebographically demonstrated by the second exposure in dynamic intraosseous phlebography. In the phlebograms of Group I type A the musculo-venous pump in the leg had a normal function. Most or all of the contrast medium had disappeared from the veins of the lower leg in the second exposure.

Fig. 13 a, b and c represent the author's conception of the venous pump in patients with primary varicose veins.

Fig. 14 a and b are phlebograms of Group I type A.

TABLE III

Records the subjective symptoms noted on the day of admittance in the various phlebographic groups together with the number of leg ulcers

Symptoms	Group I a 48	Group I b 1[illegible]	Group II a 130	Group II b 49	Group III 68
Without	21 (4[illegible])	3 (25)	28 (22*)	2 (4)	1 (1.5)
Heaviness & tiredness	21 (4[illegible])	8 (67)	5[illegible] (43)	31 ([illegible]0)	3[illegible] ([illegible])
Slight pain	1 ([illegible])	5 (42)	43 (33)	19 (39)	22 (32)
Bursting pain		1 (8)	18 (14)	13 (27)	31 (46)
Restless legs & night cramp	1 (2)	3 ([illegible])	19 (14)	6 (13)	13 (19)
Leg ulcers	[illegible] (14)	4 (33)	69 (50)	50 (81)	9 (1[illegible])

*) Of the eighteen patients thirteen had deep veins reminiscent of Group III.

CHAPTER IX
THE VENOUS RETURN FROM THE LOWER LEG IN PATIENTS WITH PRIMARY VARICOSE VEINS AND INCOMPETENT COMMUNICATING VEINS OF THE LOWER LEG (GROUP II TYPE A)

Isolated incompetence of the communicating veins in the lower leg was demonstrated clinically in four cases In all the rest of the patients in this group incompetence of the communicating veins was accompanied by saphenous varicosities The incompetent communicating veins practically always belonged to the group of ankle perforating veins

The clinical symptoms were graver than met with in Group I type A (simple varicose veins) and the frequency of leg ulcers much higher (Table III)

Group II type A contained patients with idiopathic incompetence of the ankle perforating veins as well as a number of cases with phlebographic signs of an earlier attack of deep thrombophlebitis The thrombotic process had practically always left the popliteal valves intact (Table II) In the evaluation of the function of the venous pump in Group II type A it will be of interest to see whether the incompetent valves in the postthrombotic deep crural veins have any additional detrimental effect on the pump function when compared with the cases where the deep veins were normal and no history of deep thrombophlebitis could be elicited

Subcutaneous and intramuscular tissue tensions In the following evaluation it is assumed that the subcutaneous and intramuscular tissue tensions are approximately the same as the values found in normal extremities Measurements from patients with chronic venous insufficiency are not available A priori one would assume that the subcutaneous tissue tension is altered by induration and ulceration

Venous pressure measurements In the quiet standing position the pressure in the saphenous veins was found to correspond to the expected hydrostatic pressure at each level In the presence of saphe

nous incompetence the normal gradual fall in venous pressure during rhythmic muscular activity did not take place

The pressure in the popliteal vein fluctuated about a mean level which corresponded to the hydrostatic pressure at this point The excursions were modest

The pressure in the deep crural and in the ankle perforating veins has never been measured

A Diastole II

As in the normal leg and in the leg with simple varicose veins serial phlebography performed with the patient in the motionless semierect position showed a slow proximal flow of the contrast mixed blood in the deep veins The speed varied between 1 and 2 cms per second In the phase of steady flow the valves in the deep crural veins and the popliteal vein must be assumed to be open and the pressure at any given level in the deep veins must be somewhere near the calculated hydrostatic pressure of a column of blood reaching to the level of the heart The difference in tension in the surrounding tissues would see to it that the pressure is slightly higher in the deep veins than in the subcutaneous veins

When the valves in the ankle perforating veins are incompetent the blood would thus be expected to flow from the deep veins into the saphenous varicosities in Diastole II

The first exposure in Group II type A confirms this assumption When the contrast mixed blood reaches the level of the incompetent ankle perforating vein some of the contrast medium is seen to seek its way towards the periphery and a section of the subcutaneous net work becomes visible (Figg 16 17 18)

The contrast medium is slightly heavier than blood It is thus conceivable that a peripheral flow of contrast can be found together with a central flow of blood (Greitz (1955) That the direction of the blood stream through the incompetent ankle perforating veins is in fact towards the periphery can be directly observed by means of the back flow test during operation When an incompetent ankle perforating vein is cut at the fascial level the central segment will bleed towards the periphery This is seen even when the extremity is raised above the level of the heart A back flow is not observed when the valves in the communicating veins are competent (The phlebographic competence or incompetence of the ankle perforating veins was controlled by means

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Venous pressure measurements In the quiet standing position the pressure in the saphenous veins was found to correspond to the expected hydrostatic pressure at each level In the presence of saphe

of the back flow test during operation in a large part of the present material. A satisfactory correlation was found (Table IV).

Thus the evidence at hand is in favour of the assumption that the direction of the blood stream through the incompetent ankle perforating veins is towards the periphery during Diastole II. The rate of flow must be imagined to be rather slow and the driving force modest.

B. Systole

At the onset of muscular contraction the tension in the subfascial compartment rises steeply towards the maximum values of 700—1200 mm H_2O. The highest values are found at the level of the ankle perforating veins. The blood is squeezed upwards into the popliteal vein and outwards through the incompetent communicating veins into the saphenous veins. The outward expulsion of blood is very strikingly demonstrated during operation. Even when the leg is elevated muscular contraction will effect a spurt of blood from the cut central end of the incompetent ankle perforating vein.

The standard technique in dynamic intraosseous phlebography gives no direct information as to what happens to the contrast medium during Systole but the "back flow test" demonstrates how the very high systolic subfascial pressure is directly transmitted into the subcutaneous network in the ulcer area through the pressure leak formed by the incompetent ankle perforating vein.

C. Diastole I

At the cessation of Systole the intramuscular tension presumably falls to at least the same low level as has been measured in the normal extremity at rest (50—110 mm H_2O). As the supporting external pressure falls away the pressure in the by now partially empty deep trunks falls below the hydrostatic pressure in the popliteal vein and the popliteal valves close. The pressure in the subcutaneous veins is now higher than in the deep veins and a central flow through all the communicating veins — competent as well as incompetent — becomes possible.

The central flow from the periphery and the increasing inflow from the muscles fill the deep trunks where the pressure immediately will begin to rise again.

The second exposure in dynamic intraosseous phlebography shows that the contrast medium which formerly was found in the incompetent ankle perforating veins and the adjacent parts of the subcutaneous

system has been sucked into the deep veins often leaving both the subcutaneous and the communicating veins free of contrast As this *is seen in Diastole I after the third muscular contraction* one must imagine that during the three cycles which separates the two exposures a continuous to and fro flow has taken place between the deep and subcutaneous systems via the ankle perforating veins

The second exposure shows retention of contrast in the deep trunks but the segments below the level of the incompetent ankle perforating veins are as a rule empty (Figg 16 17 18) The column of contrast medium in the deep veins has moved upwards into the most proximal parts and into the popliteal vein Thus while the function of the venous pump is seen to be impaired muscular activity still seems to have some effect on the transport of blood

The importance of the deep crural valves for the pump mechanism in the lower leg

It is very interesting to notice that postthrombotic valvular destruction in the deep veins of the leg does not seem to add to the degree of impairment of the venous pump in Group II type A as long as the popliteal valves are normal

Group II type A contained 27 patients with phlebographical signs of postthrombotic valvular destruction in the deep crural veins and a history that confirmed the x ray diagnosis Clinically these patients were of the same type as the majority of the group which had an idiopathic incompetence of the subcutaneous and communicating veins The percentage of ulcers was identical and the subjective complaints did not differ in character (Table II and III)

Phlebographically the degree of impairment of the venous pump was identical (Fig 18)

In this connection it is of interest that the few patients in Group I type B who all had a history of deep thrombophlebitis which was confined to the deep crural veins had a phlebographically normal function of the venous pump *The communicating veins were competent*

The vast majority of the phlebograms in Group II type A with sequels of deep crural thrombophlebitis had normal popliteal valves (Table II)

Thus it seems as if the function of the venous pump in the lower leg is dependent upon competent valves at the outlets from the musculo fascial compartment (the communicating veins and the popliteal veins) Incompetence of the ankle perforating veins will effect an impairment of the function of the venous pump Valvular destruction in

side the musculo fascial compartment does not add to the degree of impairment, as long as the valves in the popliteal vein are competent What will happen when not only the crural valves but also the popliteal valves are destroyed will be discussed when dealing with the Group II type B

Figg 15 a b and c represent the cyclus Diastole II Systole and Diastole I in Group II type A

Figg 16 17 and 18 are typical phlebograms from Group II type A

CHAPTER X

THE VENOUS RETURN FROM THE LOWER LEG IN PATIENTS WITH VARICOSE VEINS INCOMPETENT COMMUNICATING VEINS AND TOTAL VALVULAR DESTRUCTION IN THE DEEP CRURAL AND THE POPLITEAL VEINS

(Group II type B)

All the patients in Group II type B had roentgenological signs of previous deep thrombophlebitis In the overwhelming majority the thrombotic process had involved the popliteal as well as the deep crural trunks (Table II) These patients had as a group severe symptoms of chronic venous insufficiency and the percentage of leg ulcers was very high (81 per cent) (Table III)

Dynamic intraosseous phlebography failed to show any signs of an active pump function after muscular contractions and in the few patients investigated by means of serial phlebography the contrast medium was seen to flow slowly upwards through all the veins of the leg The subcutaneous veins became filled via the incompetent ankle perforating veins (which always were present) and the rate of flow was quite unaffected by muscular activity

Intramuscular and subcutaneous tissue tension Until further evidence is at hand it will be assumed that the intramuscular and subcutaneous tissue tensions in patients with venous insufficiency in Group II type B are identical with those measured in normal subjects A priori one would assume that the induration and ulceration so common in this group would change the subcutaneous tissue pressure

system has been sucked into the deep veins often leaving both the subcutaneous and the communicating veins free of contrast As this is seen in Diastole I after the third muscular contraction one must imagine that during the three cycles which separates the two exposures a continuous to and fro flow has taken place between the deep and subcutaneous systems via the ankle perforating veins

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The importance of the deep crural valves for the pump mechanism in the lower leg

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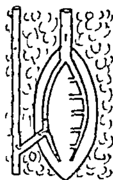
Group II type A contained 27 patients with phlebographical signs of postthrombotic valvular destruction in the deep crural veins and a history that confirmed the x ray diagnosis Clinically these patients were of the same type as the majority of the group which had an idiopathic incompetence of the subcutaneous and communicating veins The percentage of ulcers was identical and the subjective complaints *did not differ in character (Table II and III)*

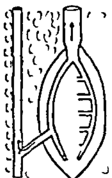
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The vast majority of the phlebograms in Group II type A with sequels of deep crural thrombophlebitis had normal popliteal valves (Table II)

Thus it seems as if the function of the venous pump in the lower leg is dependent upon competent valves at the outlets from the musculo fascial compartment (the communicating veins and the popliteal veins) Incompetence of the ankle perforating veins will effect an impairment of the function of the venous pump Valvular destruction in





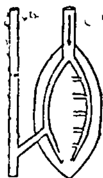


Fig 19 a b and c represent in schematic form the function of the venous pump in the lower leg during Diastole II Systole and Diastole I in an extremity with varicose veins incompetent communicating veins and total deep valvular destruction including the popliteal valves *(Group II type B)*

Fig 19 a Diastole II During the phase of slow steady flow the blood passes upwards driven by the vis a tergo Owing to the difference in pressure blood is driven outwards from the deep veins via the incompetent communicating veins into the subcutaneous system The pressure gradient is moderate and the rate of flow slow Hydrostatic forces are unhindered in all systems

Fig 19 b Systole The steep increase in pressure caused by muscular contraction drives the blood in the deep trunks out of the fascial compartment into the popliteal veins and — via incompetent communicating veins — out into the subcutaneous system

Fig 19 c Diastole I Immediately after muscular activity the pressure inside the fascia cruris falls abruptly This would in a normal extremity cause the popliteal valves to close When the popliteal valves (together with the deep crural valves) are incompetent the inversed pressure gradient will cause a rush of blood backwards into the deep crural veins At the same time the by now higher pressure in the subcutaneous veins will effect a central flow into the deep veins through the communicating veins

Thus the initial low pressure inside the fascia will rise very rapidly until the pressure exceeds that of the popliteal and subcutaneous veins Diastole II is quickly reestablished and Diastole I must be of very short duration The amount of blood transferred from the subcutaneous into the deep veins must consequently be very small

gards the incompetent ankle-perforating veins and the slight rise in pressure in the popliteal vein at this moment is in all probability caused by the inrush of blood from the crural veins

The standardized dynamic intraosseous method of phlebography does not show what happens to the contrast medium during systole

As in all other forms of venous incompetence hitherto investigated a central flow of blood through the communicating veins does not seem possible during Diastole II and Systole in Group II type B

C Diastole I

At the cessation of contraction the deep veins inside the musculo fascial compartments in the lower leg are imagined to contain much less blood than before The high intramuscular tension falls abruptly to at least the resting values of 50—110 mm H O The immediate result must be a sharp fall in venous pressure At this moment normal popliteal valves would close but in these extremities the popliteal valves are absent (Table II) as are the valves in the deep veins of the lower leg

If we imagine the deep crural veins to be empty or nearly empty and the pressure much lower than the pressure in the popliteal vein the unhindered hydrostatic force will cause an immediate rush of blood backwards from the deep veins in the thigh and at the moment that an unbroken column of blood is established throughout the deep system the venous pressure must become equal to the calculated hydrostatic pressure at all levels The only imaginable hindrance for the establish ment of an unbroken column of blood where the valves are absent is a blockage caused by intimal contact in an absolutely empty segment of vein In theory this may occur but cannot be expected to last for more than an exceedingly short time

The evidence at hand thus indicates that Diastole I is exceedingly short in Group II type B and that the state of steady flow with full hydrostatic pressure at all levels (Diastole II) is established almost at once following muscular relaxation

In normal subjects and in Group I type A and Group II type A Dia stole I was found to be the only phase in which a central flow was possible through the communicating veins into the deep veins If it *exists at all in Group II type B* Diastole I must be so short that the volume of blood exchanged between the subcutaneous and deep veins of the leg is almost negligible In these patients the saphenous varicosi ties will not empty during the Perthes test

In normal subjects and in other types of chronic venous insufficiency discussed above *Diastole I was seen to be favorable for the outflow* from the muscular veins into the deep trunks In Group II type B the period of low pressure in the deep trunks must be extremely short and the flow in the minute muscular veins and venules must be imagined to take place against a practically constant high pressure

The second exposure in dynamic intraosseous phlebographs shows what has happened to the contrast medium after three cycles of contraction and relaxation. Nothing much seems to have happened. The contrast is found in the deep veins, the communicating veins and the subcutaneous veins and has reached a higher level than in the first exposure but not higher than could be expected where the vis a tergo is the sole effective driving force (Figg. 21, 22).

Thus a total destruction of the valves in the communicating veins and the deep veins of the leg and thigh (at the outlets from the musculo-fascial compartment) causes a total destruction of the venous pump.

Figg. 19 a, b and c represent the cyclus Diastole II, Systole and Diastole I in Group II type B.

Figg. 21 and 22 are phlebograms of Group II type B.

CHAPTER XI
THE VENOUS RETURN FROM THE LOWER LEG IN PATIENTS WITH VARICOSE SAPHENOUS VEINS AND IDIOPHATHIC INCOMPETENCE OF THE DEEP VEINS COMPETENT COMMUNICATING VEINS

(Group III)

All the patients with phlebograms of this pattern had varicose saphenous veins. The number of leg ulcers in the group was low (Table III) and the percentage almost identical with that found in Group I type A (simple varicose veins). There was however a striking difference in the character of the subjective complaints. A very common symptom in Group III was the severe bursting pain in the leg which was never met with in patients with simple varicose veins in the present material (Table III).

The phlebograms of Group III showed normal deep veins of the leg in so far as the contours of the veins and the valvular structure did not show any signs of postthrombotic changes. The diameter of one or several of the deep veins was however much wider than seen in the normal control material. The diameter of the fibula measured ten cms below the tip of the capitulum was taken as a means of comparison. In the normal control material the deep veins generally had a diameter

between one third and half that of the fibula while the majority of the phlebograms in Group III showed deep veins which at some points had diameters equal to or wider than the fibula

The communicating veins in the leg were phlebographically competent Incompetent communicating veins were found together with enlarged deep veins but this mixed group was listed under Group II type A

In most cases the diameter of the popliteal veins was rather wide but no attempt was made — in the present material — to determine the normal caliber of this vein

In the second exposure contrast was seen in one several or all deep veins but sometimes only in an apparently especially wide segment of a vein As this phenomenon never was seen in the normal control material it was regarded as a sign of incompetence of the venous pump mechanism The degree of incompetence varied from complete destruction to slight impairment

Subcutaneous and intramuscular tissue tension Until further evidence is at hand the subcutaneous and intramuscular tissue tensions will be considered identical with the tensions measured in normal subjects

Venous pressure measurements Venous pressure in the varicose subcutaneous channels is equal to the hydrostatic pressure of a column of blood reaching to the level of the heart It may be assumed that the pressure in the popliteal vein behaves as in normal individuals patients with simple varicose veins and patients with total valvular destruction that is it fluctuates about a mean value roughly equal to the hydrostatic pressure at this level

The pressure in the communicating veins and in the veins inside the musculo fascial compartment has never been measured

A Diastole II

The first exposure shows that the contrast medium has filled the deep veins of the leg and sometimes the popliteal vein Contrast is not seen outside the fascia cruris

Diastole II is the phase of slow steady flow The valves are open in the subcutaneous as well as in the deep veins and consequently the pressure at any given level must be equal to the weight of a column of blood reaching to the level of the heart The difference in tension in the surrounding tissues tends to make the effective pressure in the deep veins higher than in the subcutaneous varicosities with the result that

the competent valves in the communicating
flow through these veins is therefore not l

B Systole

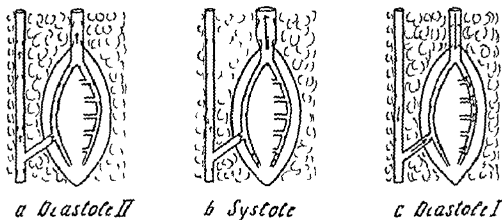
At the onset of muscular contraction the
anterior tibial muscles was observed *to rise* s
vel of 50—100 mm H_2O to a maximal figu
lower third of the soleus These measurem
extremities

Wells Youmans & Miller (1938) who investi
traction pressure in different muscles found that th
reached during maximal contraction depended up n the
the fascial sheath The soleus and the tibialis anterior m s t s h ve strong fascias while the gastrocnemius and the rectus femoris where the rise in intramuscular tension was much more modest (Fig 6) have less well developed fascial *coverings*

The reason why some deep veins of otherwise normal appearance seem to be dilated and empty poorly after muscular activity is still unknown Several possible explanations offer themselves One possibility is that the tone of the vein wall is lowered in the same manner as seen in the early stages of primary saphenous varicosities (*Arnoldi* 1957 and 1961 a) The dilation might also be the result of a shrinking of the muscular tissue inside the fascial sheaths the loss of support giving rise to a secondary widening of the veins and a less effective expulsive power in the pump section — A relaxation of the fascial structures would according to the investigations mentioned above bring about a fall in maximum tension during contraction and possibly give room for a secondary widening of the deep veins Finally a severe phlebosclerotic process may lead to a state with wide rigid veins which cannot be compressed by the surrounding muscles A phlebosclerotic degeneration is always preceded by a loss of elastic tissue

Research in this field is non existing The theory of a hormonally induced loss of tone is perhaps supported by the fact that many of the patients in Group III gave a history of increasing complaints at the time of menstruation Visible muscular atrophy was never demonstrated in the extremities with phlebograms of this type

The theory of fascial hypotrophy or relaxation as a factor in venous insufficiency has recently led to the development of a new surgical approach in chronic venous insufficiency in which the fascia over the



Figg 23 *a b and c* represent in schematic form the function of the venous pump in the lower leg during Diastole II Systole and Diastole I in an extremity with varicose veins and »primary deep incompetence« Competent communicating veins (*Group III*)

Fig 23 *a* Diastole II In the phase of steady flow the valves are open and the hydrostatic forces have full effect in the deep as well as in the varicose superficial veins The driving force = the vis a tergo The slightly higher effective pressure in the deep system keeps the valves in the communicating veins closed

Fig 23 *b* Systole The high pressure inside the fascia cruris expells the blood via the popliteal vein The distal route and the route through the communicating veins are blocked by competent valves

Fig 23 *c* Diastole I (could be explained in the following way) At the end of muscular contraction the pressure inside the fascial compartment falls steeply This makes a filling from the varicose subcutaneous veins possible The resulting refilling af the deep trunks reaches a point where the distension of the wide deep veins overcomes the competence of valves including the popliteal valves As soon as an unbroken column of blood is established the hydrostatic forces have full effect throughout the system

Should the wide deep veins be the seat of phlebosclerotic changes the shortening of Diastole I would seem to become even more pronounced

gastrocnemius muscles is tightened by duplication (*Aslar* (1961) idea was first proposed by *Gullmo* (1959) One of the beneficial of the time honoured treatment with pressure bandages could establishment of an extra fascial sheath over the muscles lower leg

The deep veins in the lower fifth of the leg were as a rule of wider in Group III and the valves in the communicating vei ... the result of muscular contraction must therefor ... is driven upwards into the popliteal vein Standar

intraosseous phlebography does not show what actually happens to the contrast during Systole

C Diastole I

As the muscles relax the high intramuscular pressure falls to about the same level as measured during Diastole II and the pressure in the deep veins of the leg presumably falls parallel with the intramuscular tension The pressure in the popliteal vein falls slightly but the result will be a lower pressure below the popliteal valves than above If the popliteal valves are normal they will close immediately

The apparent dilation of the deep veins in Group III may involve a segment of a vein or all the deep veins visible in the phlebogram Should the popliteal vein be involved together with the deep crural veins one may imagine a state in which the valves no longer are competent When an unbroken column of blood is established the pressure in the deep veins will become equal to the full hydrostatic pressure of a column of blood reaching to the level of the heart

Diastole I will probably never become as short as in Group II type B as the valves must be supposed to be competent during the first part of the period of central flow through the communicating veins and from the muscular tributaries until a certain degree of dilation has been reached and contact between the valvular rims no longer is possible

In an extremity of this type the period most favorable for the central flow from the smaller muscular veins into the deep crural trunks is shortened as was found to be the case in Group II type B

Extremities with total postthrombotic valvular destruction (Group II type B) differed considerably from those with primary deep incompetence (Group III) While 81 per cent of the postthrombotic patients had leg ulcers this was only seen in 14 per cent in Group III (Table III) All the postthrombotic legs in Group II type B had incompetent ankle perforating veins but in Group III the communicating veins were competent

A look at Table III will show that the most serious subjective complaints the severe bursting pains in the lower leg are almost exclusively found together with total valvular destruction (Group II type B) or deep idiopathic insufficiency (Group III) Most of the patients in Group II type A with this symptom had deep veins reminiscent of Group III

The theory does not seem too far fetched that the bursting pains in

the leg are caused by the practically constant high pressure in the deep veins of the leg (shortening or disappearance of Diastole I)

The severe subjective complaints in the leg not infrequently persist after radical surgical treatment of varicose veins and incompetent communicating veins In the author s experience these symptoms are as a rule relieved after resection of the popliteal vein

Isolated retention of contrast in a dilated section of vein is difficult to explain A small reservoir may be a variation of normal physiology just as faint traces of contrast confined to the valvular sinuses are considered normal Retention of contrast in a larger segment of wide caliber is however definitely abnormal and was never met with in the normal control material The cause of this local retention of contrast medium is unknown and an attempt at explanation is deemed futile as long as information about the venous and intramuscular pressure in the musculo fascial compartment are wanting in this type of chronic venous insufficiency

Figg 23 a b and c represent the cyclus Diastole II Systole and Diastole I in the typical cases of primary deep insufficiency

Figg 24 and 25 are phlebograms from Group III

CHAPTER XII

THE AUTHOR S CONCEPTION OF THE STRUCTURE OF THE VENOUS PUMP

Fig 2 represents the conception of the structure of the venous pump which is prevalent in the physiological literature at present

The evaluation of the conditions for the venous return described in the present paper which is based upon the phlebographic examination of the function of the three segments of the pump inside the deep crural fascia has together with the results of measurements of venous pressure and tissue tension given rise to the conception of the structure of the venous pump in the lower extremity which is illustrated by Fig 26

The central stem (popliteal femoral and external iliac veins) which i arsely valved and for the most part embedded in fat or in loose

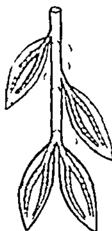


Fig ... presentation of the auth... ...n of the structure of th... ...pump in the lower extrem...

Th... ...venous pump in the l... ...represented as a set ...f pum... ...is attached to the central ... ...vein (popliteal femoral) Each pump ...ection consists of a mus... ...f muscles ensheathed by fascia ...g ther with the vessels F... ...are found in the lower leg Fig 1 The upper pump section in Fig ... might represent the section drained b... th... deep femoral vein (see text)

connective tissue has a passive collecting function while the densely valved veins inside the musculo-fascial compartments are more actively engaged by the pump mechanism The practically unaltered mean pressure in the central stem during muscular activity and the great variations in pressure which take place in the veins of the pump sections are in favour of this conception

The loose support of the environment of the central stem and the elasticity of the vein wall enable these veins to act as a buffer for the great variations in pressure which are found where the pump sections emerge into the collecting veins

The function of the venous pump of the lower extremity as a whole is facilitated by the alternating action of the pump sections The few valves in the central stem are usually placed below the entrance of the veins from the pump sections

It seems as if the fascial structure and thus the force of the expulsive power of the pump segment is finely adjusted to the hydrostatic pressure at each level under normal conditions (Fig 6) and that further investigations on the musculo fascial structures would be worth while in patients with chronic venous insufficiency

The phlebographic examination of the function of the pump sections in the lower leg demonstrated the importance of the valves at the outlets from the musculo-fascial compartments The pump function might become deficient from a leak of blood through the incompetent communicating veins out into the subcutaneous veins Lack of func

of the valves at the upper outlet in the popliteal vein (together with incompetence of the crural valves) results in a very grave impairment of the pump function

On the other hand it did not seem as if the valves inside the musculo fascial unit are of importance for the function of the pump section as a whole The main function of these valves is probably — as *Jager* (1936) suggested — to act as a protection for the venules and capillaries against too violent variations in venous pressure

The vein valves are only one of the factors determining the function of the pump mechanism but at present it is the only factor which has been studied to any extent The impaired function in Group III suggests that a disturbance in other factors necessary for the perfect function of the venous pump may be of importance

PART III
THERAPEUTIC CONCLUSIONS

The analysis of the phlebographic material (Arnoldi 1961 a and b) and the evaluation of the function of the venous pump in the various forms of chronic venous insufficiency presented above has necessarily influenced the author's conception of the rational treatment of venous disorders in the lower extremity. As was to be expected the conclusions arrived at have confirmed established ideas to a large extent but they have also emphasized the importance of an exact diagnosis of the type of insufficiency in the individual case. The phlebographic investigation has illuminated the importance of the extent of the initial attack of deep thrombophlebitis for the frequency and severity of the late postthrombotic sequelae and it has perhaps increased our understanding of the origin of the severer subjective complaints in chronic venous insufficiency.

CHAPTER XIII
THE ACUTE STAGE OF DEEP THROMBOPHLEBITIS

Signs of postthrombotic changes in the deep veins were found in Group I type B, Group II type A and Group II type B.

In Group I type B the venous pump was seen to function in a normal way (definition) and the popliteal valves were as a rule intact.

In the postthrombotic cases in Group II type A the signs of postthrombotic changes were confined to the deep crural veins while the popliteal valves were normal in the large majority of cases (Table II).

The impairment of the function of the venous pump was due to in competent communicating veins and the postthrombotic valvular de struction did not seem to add to the degree of incompetence The per centage of leg ulcers in the "idiopathic" and postthrombotic material in Group II type A was identical

In Group II type B the thrombotic process had involved the popliteal as well as the crural valves The phlebograms showed a total destruction of the function of the venous pump and the percentage of ulcers was very high (81 per cent) (Table III)

Thus it seems that a thrombotic process confined to the deep veins of the lower leg has a better long term prognosis than a process which also involves the veins at a higher level Our treatment of acute deep thrombophlebitis should recognize this fact

The diagnosis of acute deep thrombophlebitis should be established at the earliest possible stage and the classical symptoms of phlegmasia *should not be allowed to develop The therapeutic procedures should* be applied with an eye to a speedy prevention of the proximal progress of the thrombus

Table II is of interest as it shows the history of the treatment in the acute phase of thrombophlebitis in the patients in the postthrombotic material in Group II types A and B While two thirds of the patients in Group II type A had been treated with heparin only eight per cent of the patients in Group II type B had had this treatment Dicoumarol did not seem to have influenced the course of the disease in any favorable direction when employed as the only anticoagulant

It is of course realised that the material presented in Table II is small The evidence of the table such as it is does however stress the im portance of the choice of anticoagulants With a slow acting anti coagulant of the dicoumarol type there is a definite risk that the ascending thrombotic process may reach the important popliteal valves before a full effect on the coagulability of the blood has been obtained with the result that the risk of grave chronic sequelae will be con siderably increased

It is felt necessary to stress this point in view of the tendency in some clinics to rely on preparations of the dicoumarol type as the sole anti coagulant in cases of manifest deep thrombophlebitis It may well be that no significant difference can be found in the rate of embolic incidents during the acute phase whether heparin or dicoumarol is used Fatal embolism is a comparatively rare occurrence in the days of early mobilisation and prophylactic anticoagulants Grave po

sequelae have however been found in the majority of the extremities which have been followed through the years after the acute attack

The evidence of the present investigation indicates that the severity and frequency of the postthrombotic sequelae may be reduced when the thrombotic process is confined to the veins inside the musculo fascial compartment Only heparin acts quickly enough to stop the process before it reaches the popliteal valves

CHAPTER XIV
SURGICAL THERAPY IN CHRONIC VENOUS INSUFFICIENCY

When considering the therapeutic conclusions drawn from the present evaluation of the function of the venous pump it is practical to distinguish between the subcutaneous manifestations (oedema induration and ulceration) and the subjective complaints especially the graver forms (the "bursting" crural pains)

A Ulcus cruris venosum

According to the prevailing conception gravitational oedema is the first step in the development of the sequence oedema — induration — ulceration A constant high pressure in the venules and the venous ends of the capillaries is responsible for a filtration oedema which when persistent causes a proliferation of fibrous tissue and a diminution of the arterial supply in the subcutis The increasing fibrosis leads to induration and devitalisation and finally even slight traumatisation will cause a breakdown in the skin and subcutis — ulceration Healing will not occur as long as the venous pressure remains high in the ulcer area and the oedema persists

It is strikingly demonstrated during operation that the pathologic processes present in the tissue in the ulcer area are confined to the skin and subcutis Under the deep fascia the muscles look completely normal to the naked eye It has been shown that the increase in leg volume seen when oedema is present is restricted to the subcutis (Arnoldi 1959)

The high venous pressure — hydrostatic or contraction pressure (Systole) is transmitted to the capillaries in the ulcer area by way of the varicose saphenous veins and the incompetent ankle perforating veins

Table II shows that incompetent communicating veins (practically always of the ankle perforating type) were present together with saphenous varicosities in 119 extremities with ulcers Only *20* cases were found without phlebographically demonstrable incompetence of the communicating veins These cases all had varicose saphenous veins Incompetence of the ankle perforating veins was found to embarrass the function of the venous pump Simple varicose veins did not have this effect

The rational surgical treatment of oedema induration and ulceration seems to be a radical elimination of the pressure leaks formed by the incompetent saphenous and communicating veins In the author s experience this is best done by *radical exstirpation of the varicose saphenous veins* combined with operative closure of the incompetent ankle perforating veins a m Cockett

B Surgical treatment of severe pains in chronic venous insufficiency

It has been the author s priviledge while working with Professor Gunnar Bauer in Mariestad to observe the effect of popliteal resection on a considerable number of patients with the more severe forms of chronic venous insufficiency *Bauer* (1959) has reported on the results of popliteal resection as a treatment for leg ulcers According to the author s *much more limited experience* with this type of treatment the most striking effect of popliteal resection is *the often prompt disappearance of the sometimes invalidating bursting pains felt diffusely in the leg* pains that sometimes have led the patients to ask for *amputation*

The effect and the rationale of the popliteal resection is but *imperfectly understood* and *the various explanations offered do not seem entirely satisfactory*

As seen from Table III bursting pains were as a rule found together with deep venous incompetence and in the evaluation of the function of the venous pump it was proposed (Chapter XI) that these pains might be due to the disappearance or shortening of Diastole I *that is to a practically constant high pressure in the deep crural veins* and their muscular tributaries

Phlebographic examinations by means of the dynamic intraosseous method are as yet comparatively few as regards the result of popliteal resection upon the function of the venous pump. While some phlebographic examinations have indicated a better function of the venous pump after operation, others have shown an unchanged picture. No correlation between the effect of the operation on the clinical signs and symptoms and changes in the phlebographic pattern has yet been demonstrable.

When the popliteal vein is resected the blood must find its way upwards through the collaterals which are supposed to have normal valves and are of a smaller caliber. (That an extensive potential collateral system exists is evident from the fact that radical saphenektomy, ligation of incompetent communicating veins and popliteal resection may be performed as a one-stage operation without noticeable post-operative oedema.)

If these premises are correct the relief of crural pain could be explained in this way. After popliteal resection the blood will be squeezed upwards through the para-popliteal collaterals (and outwards through the incompetent ankle perforating veins unless ligation is done at the same time). At the cessation of Systole the pressure in the musculo fascial compartments in the lower leg will fall below the pressure in the femoral veins and the competent valves in the collaterals will prevent a backward rush of blood. The elimination of the pressure gradient between the femoral and crural veins will be retarded. The effect of popliteal resection would thus be the reestablishment of a Diastole I.

A thorough phlebographic evaluation of the effect of popliteal resection on the function of the venous pump will not be possible until a material is at hand in which popliteal resection has been performed upon patients belonging to Group II type B who have had a Cockett's operation for incompetent ankle perforating veins done at an earlier stage and in whom the result of this operation has been controlled phlebographically before the popliteal vein is resected.

The author would reserve popliteal resection to cases with severe pains in the leg caused by chronic venous insufficiency and preferably when the patient describes the pain as being of a diffuse bursting character. In the author's experience ulceration is better treated by elimination of the subcutaneous pressure leaks, saphenektomy and ligation of incompetent communicating veins.

CHAPTER XI

INDICATIONS FOR DYNAMIC INTRAOSSEOUS PHLEBOGRAPHY

The author's experience with dynamic intraosseous phlebography encompasses more than 600 examinations. In two of these cases a necrotic breakdown of the skin occurred over the lateral malleolus, which was used as site of injection in the first phlebograms. No other complications have been met with. At this point it should be emphasized that intraosseous injections must be performed under scrupulously aseptic conditions. Cases of osteitis and osteomyelitis have been reported following all forms of intraosseous injections (*Søndergaard* (1946), *Heinild, Søndergaard & Tudvad* (1947)). Our experience shows, however, that if performed under aseptic conditions the intraosseous method has a very low percentage of untoward complications.

The clinical evaluation of the extremity with chronic venous insufficiency is often not at all easy when the patient is seen for the first time.

In the large majority of patients with simple varicose veins the diagnosis is simple enough and the presence of typical incompetent ankle-perforating veins should be demonstrated without too much difficulty in a great many cases.

The presence and localisation of incompetent ankle-perforating veins and atypical communicating veins may, however, be very difficult to demonstrate in patients with severe subcutaneous manifestations (oedema, widespread induration or large ulcers). If the surgeon wishes to limit the extent of his exploratory incisions, a preoperative phlebographic demonstration of the incompetent communicating veins is desirable.

A history of deep thrombophlebitis may be elicited in most patients with postthrombotic changes in the deep veins, but both the history and the clinical examination are often unable to decide how far the

thrombotic process has proce[illegible] rt from the academic interest the question is import[illegible] who may consider a popliteal resection as a remedy f[illegible] evere pains or who may wish to treat the venous ul[illegible] A popliteal resection is in the author's opinion [illegible] the popliteal valves have a normal function but may [illegible] tive therapy in cases with total valvular destruction [illegible] lebographic evaluation is essential

Legs with simple varicose ve[illegible] ulcer and moderate oedema but with severe and c[illegible] are quite often the seat of a primary idiopathic in[illegible] eep veins The only possible way to come to a corre[illegible] ans of a functional type of phlebography

In general it may be said t[illegible] who treat chronic venous insufficiency schematic[illegible] bography is really non-existent while it is essent[illegible] to make a proper diagnosis and to treat their pat[illegible]

What type of phlebography [illegible] This question cannot be answered definitely [illegible] the wishes of the examinator If a total filling o[illegible] lower extremity is desired the intraosseous me[illegible] ed as it will only show the deep veins of the le[illegible] all the deep veins) and the incompetent commun[illegible] lower leg The concentration of contrast is gener[illegible] any clear-cut morphological diagnosis above the[illegible]

Finally the author has beco[illegible] e intraosseous technique as performed in the [illegible] of phlebography is not suitable for the demonstr[illegible] ombotic affections in the lower leg For this purpos[illegible] be preferred which can be depended upon to show [illegible] veins

The limited area of contrast [illegible] ossibility of a shift of contrast medium from one ve[illegible] nother makes the intraosseous method ideally suit[illegible] tional evaluation If this type of examination is preferred [illegible] intraosseous phlebography is — in my experience — superior [illegible] other known method

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM nr 65

FROM THE ORTHOPAEDIC RESEARCH LABORATORIES (HEAD GÖRAN C. H. BAUER M. D.)
AND THE ORTHOPAEDIC CLINIC (HEAD SOPHUS VON ROSEN M. D.),
MALMÖ GENERAL HOSPITAL, UNIVERSITY OF LUND, MALMÖ, SWEDEN

AN EPIDEMIOLOGIC STUDY OF CERVICAL AND TROCHANTERIC FRACTURES OF THE FEMUR IN AN URBAN POPULATION

ANALYSIS OF 1 664 CASES WITH SPECIAL REFERENCE TO ETIOLOGIC FACTORS

BY
PER AXEL ALFFRAM

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Financial support was obtained from the Medical Faculty of the University of Lund and the Järnhardts Stiftelse Malmo and from grants given to Professor Goran C H Bauer from the Josiah Macy Jr Foundation, New York the United States Public Health Service Grant D 1452 and from the Swedish Medical Research Council

Duncan McPherson M D assisted in the translation into English

CONTENTS

I INTRODUCTION

In the skeleton struck by severe trauma or a cancer metastasis fracture is easily explained In most fractures the etiology is more complex and it is difficult to evaluate the relative importance of various etiologic factors This investigation is an attempt at such an evaluation A large group of patients has been chosen because the complexity of the problem makes it impossible to draw general conclusions from individual patients Fracture of the proximal end of the femur has been chosen because virtually every case seeks medical advice and thus becomes known and because this fracture usually necessitates prolonged hospital care during which more information becomes available concerning the patients than is generally available concerning other fracture patients The City of Malmo has been chosen for this investigation because it provides near ideal conditions for an epidemiologic survey a limited number of hospitals serve a well defined population of relatively homogenous origin

In a previous study fractures of the forearm in the same population were evaluated with attention to the following variables sex age type of fracture and degree of trauma In the present investigation the region of the skeleton studied has been more limited but the scope of the investigation has been widened by giving attention to an additional variable the health of the probands

Based upon the results of this investigation an etiologic classification of cervical and trochanteric fractures of the femur is proposed for use in comparison of therapeutic results in epidemiologic studies and in evaluation of individual patients

II MATERIAL, METHODS, AND DEFINITIONS

A POPULATION AT RISK

Malmö is a center of commerce and industry in southern Scandinavia It is the third largest city of Sweden having 225 660 inhabitants on January 1, 1960 City authorities maintain detailed records of age, sex mortality and migration Hospital services are provided by one general hospital, one mental hospital and one geriatric hospital These circumstances have made Malmö particularly suitable for previous epidemiological studies of disease, as shown by BIORCK BLOMQUIST and SIEVERS (1957), SIEVERS and BLOMQUIST (1962) and SIEVERS (1963) in studies on arteriosclerotic heart disease by BIORCK (1955) BIORCK and HALL (1955) and HALL (1961) in investigations of rheumatic disease and by BAUER (1960) and ALFFRAM and BAUER (1962) in fracture studies The World Health Organization has recently chosen Malmö as the site of an extensive investigation of arteriosclerotic heart disease

1 *Hospital Facilities in Malmo*

During the period of this investigation the population of Malmo was served by one general hospital (MGH 1585 beds), one mental hospital (MMH, 675 beds) and one geriatric hospital (GH, 600 beds) Two small private hospitals (16 and 21 beds) were under the supervision of private physicians

Since 1945 practically all fracture cases requiring hospital care have been referred to the Orthopedic Clinic of MGH A few fractures occurring in patients admitted to MMH or GH were treated entirely at these hospitals Fractures which were treated in the two small private hospitals were radiographed at MGH

It is reasonable to conclude that during the period of the investigation, review of the records of the radiological departments of MGH MMH and GH and of the Orthopedic Clinic of MGH would reveal all cases of fracture of the proximal end of the femur diagnosed in Malmö

2 *Population of Malmö in 1950—1960*

The total population of Malmö is known for each year of the period of this investigation *The age and sex* distribution of residents over 30 years of age is recorded for 1950, 1955 and 1960 (Table 1) From 1950 to 1960 the total population of Malmo increased by less than 2 per cent per year

Table 1 *Population of Malmö in 1950 1955 and 1960*

Age groups	1950		1955		1960		Per cent women in	
	Women	Men	Women	Men	Women	Men	1950	1960
30—39	17 200	16 [illegible]10	17 455	16 278	16 931	16 532	51 5	50 6
40—44	8 632	7 734	8 813	8 189	8 951	8 614	52 7	51 0
45—49	7 337	6 451	8 675	7 693	8 894	8 2[illegible]6	53 9	51 8
50—54	6 237	5 397	7 402	6 431	8 737	7 782	53 6	52 9
55—59	5 382	4 394	6 167	5 311	7 338	6 299	55 5	53 8
60—64	4 848	3 899	5 293	4 165	6 073	4 957	55 9	55 1
65—69	4 135	3 941	4 569	3 490	4 989	3 733	56 1	57 2
70—74	3 196	2 254	3 633	2 782	4 171	2 889	58 1	59 1
75—79	1 762	1 302	2 504	1 728	2 914	2 038	57 5	58 8
>80	1 967	770	1 732	1 170	2 513	1 497	62 2	62 7

In 1952 the Parish of S Sallerup with 898 inhabitants was incorporated into Malmö No other geographic or administrative changes took place

The *natural increase in population* (the difference between the number of births and deaths) was 0 75 per cent of the total population in 1950 0 60 per cent in 1955 and 0 49 per cent in 1960 The *net gain of migration* (the difference between the number of immigrants and emigrants) was 56 per cent of the total annual increase of population in 1950 and 68 per cent and 70 per cent in 1955 and 1960 respectively Since 1930 67 to 75 per cent of the net gain in population has been composed of equal numbers of women and men between 15 and 35 years of age (Generalplan for Malmö 1959) Migration by age and sex between November 2 1961 and November 1 1962 is known (Statistiska uppgifter för Malmo stad 1963) Less than 2 per cent of inhabitants over the age of 60 moved into or out of the city during that period providing evidence of the stability of that part of the population mainly subject to fracture of the proximal end of the femur

Between 1950 and 1960 the *absolute size* of nearly all five year age groups increased During the same period the *relative size of the older age groups* also increased (Table 1) This tendency to aging of the general population conformed to a general pattern observed throughout the Western World (BERG and TILLMAN 1959 BUHR and COOKE 1959 and BOUCHER 1959)

B CLASSIFICATION OF FRACTURES

Differences in the prognosis of various types of fracture are well recognized However few studies have attempted to relate the occurrence of different types of fracture in an unselected population with age sex and

degree of trauma As this was one of the purpo es of this investigation, a suitable classification of fractures was needed

COOPER (1824) was the first to describe a cla ification of fractures of the proximal end of the femur, distinguishing cervical fractures from trochanteric fractures upon clinical and post mortem examination Since the advent of diagnostic radiology, classifications have usually been based upon the radiographic appearance of the fracture

1 *Cervical Fractures*

A more detailed definition of cervical fractures was introduced by KOCHER (1896) and elaborated by FALTIN (1924) and ANSCHUTZ and PORTWICH (1927) based upon the *anatomical localization* of the fracture These authors distinguished subcapital from intermediary fractures This classification has been used recently in experimental studies (BACKMAN 1957 FRANKEL, 1960)

The *relative position of the fracture fragments* has al.o been the ba is for classification a distinction being made between abduction and adduc tion fractures (WALDENSTROM 1924 BOHLER 1938 LINTON 1944), or valgus and varus fractures (NYSTROM 1938 SPOTOFT 1944 ODEN, 1947 HULTH 1956)

In recent years several authors have further simplified the clas ification into (a) fractures without displacement (usually equivalent to impacted fractures) and (b) fractures with di placement (CLEVELAND and FIELDING 1954 FRANKEL and PRATT 1955 FINNEY BEVERLY and EATON 1959)

LOFBERG (1924) and ODELBERG JOHNSSON (1930) advanced the theory that the *inclination of the fracture line* on the antero posterior radiograph was significant with regard to stability of the fracture this has been the ba is of cla ifications by others (HOWARD and CHRISTOPHE, 1934 NYSTROM 1935 LEHMAN 1935 PAUWELS 1935 BOHLER 1938 SPOTOFT 1944)

Impacted cervical fractures have been eparated from other cervical fractures with regard to treatment and prognosis (LINTON 1944 CARLQUIST 1947 ODEN 1947 TRUETA and HARRISON 1953 CRAWFORD 1960) LINDGREN (1924) defined impaction as an evident entrance of one frag ment or part of it into the spongy substance of the other as shown radiographically without regard to the clinical stability of the fracture ODELBERG JOHNSSON (1930) assumed it impossible to assess the stability of an impacted fracture at *one single* radiographic or clinical examination and according to NICOLE (1939) radiographic examination alone cannot establish the diagno is of impaction LINTON (1944) stated that 'from a clinical point of view a fracture which does not become dislocated when

in normal function is regarded as impacted and suggested the word 'stability' should be used instead of 'impaction emphasizing that these terms were not synonymous According to SPOTOFT (1944) CARLQUIST (1947) and CAVE (1960) impaction is chiefly encountered in valgus fractures Like NICOLE and LINTON CRAWFORD (1960) and CONWELL and REYNOLDS (1961) combined the radiographic appearance and the result of clinical examination to establish a diagnosis of impaction

2 *Trochanteric Fractures*

FALTIN (1924) and ANSCHUTZ and PORTWICH (1927) divided trochanteric fractures into an intertrochanteric and a pertrochanteric type A pertrochanteric fracture was defined as a fracture within the trochanteric region lateral to the intertrochanteric line An intertrochanteric fracture was defined as a fracture through or in the immediate vicinity of the intertrochanteric line As this fracture passes through the base of the neck of the femur GREVILLIUS (1938) proposed the term fractura colli femoris basalis a term also used by MURRY and FREW (1949) CLEVELAND et al (1959) called this fracture paratrochanteric SPOTOFT (1944) placed such basal fractures in the cervical group but a majority of authors regard them as trochanteric fractures since they are similar to pertrochanteric from the therapeutic and prognostic point of view

Some authors distinguish between stable and unstable trochanteric fractures (EVANS 1951 CRAM 1955 CLAWSON 1957 BRENNER and GRAHAM 1958) and others class them by degree of comminution and displacement of the fracture (HAFNER 1951, HUDSON and GILIBERTY 1957)

3 *Classification Used in this Study*

The anatomical classification defined by ANSCHUTZ and PORTWICH (1927) was adopted but their terms medial and lateral for the two main fracture types were replaced by the terms *cervical* and *trochanteric* (STEWART 1955) as the term lateral has so often been applied to fracture of the lateral part of the femoral neck as well as trochanteric fractures

Fractures immediately below the head of the femur were defined as subcapital and those localized between this region and the base of the proper neck of the femur were called transcervical

No distinction was made between different types of trochanteric fractures Subtrochanteric fractures defined by BOYD and GRIFFIN (1949) as occurring at the level of or below the lesser trochanter and isolated fractures of the greater or lesser trochanters were excluded

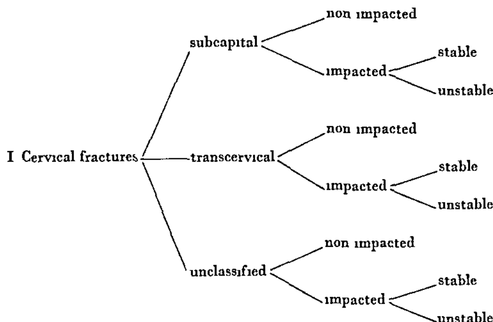
Attention was paid to the presence or absence of *impaction* as determined

from radiographs and case histories A cervical fracture was considered impacted if the initial radiographs showed either penetration of parts of one fragment into the other or no displacement of the fragments, and active or passive movements of the hip caused little or no discomfort at the time of the initial clinical examination

Fractures initially regarded as impacted which did not become displaced during conservative treatment were called *stable fractures*

The trochanteric fractures were not assessed with regard to degree of comminution or stability

The following scheme was used for the classification of fractures



II Trochanteric fractures

4 *Sources of Error in Classification of Fractures*

Using modern radiographic techniques there should be little difficulty in separating cervical from trochanteric fractures In the present series difficulty arose in only one case of mixed type, which was classified as trochanteric as it had been treated on that basis

Irregularity of the fracture surface has been noted to cause difficulty in the separation of subcapital from transcervical fractures (FALTIN, 1924, NYSTROM 1938 HULTH 1956) In this study such uncertainty was usually found in subcapital fractures where a small spike of bone was attached to the head In view of experience with endoprosthetic replacement it seemed

reasonable to classify the e as subcapital fractures as did FALTIN and HULTH

Twenty eight patients in this series gave a history of being able to walk on the injured leg although the first radiographs revealed displacement A few of these actually felt their leg give way suggesting that the fracture was stable until displacement occurred Such fractures have been classified as non impacted

C PROBANDS

1 *Selection of Probands*

Probands were residents of Malmö who had a radiographically diagnosed cervical or trochanteric fracture of the femur during the period 1949 through 1961 Two cases with incidentally noted healed fractures without a recollection of injury were excluded from this preliminary material

The records of the Orthopaedic clinic of MGH and the radiodiagnostic departments of MGH MMH and GH were reviewed for case histories and radiographs Cases at GH were found by review of all radiographs of the lower extremity done at that hospital

Two series were distinguished —

Series A Material from the 10 year period 1949—1958 composed of 1 124 fractures occurring in 1 101 patients 23 of whom sustained two fractures during this period All radiographs of these cases initial films as well as those taken at operations were evaluated by the author in collaboration with a radiologist at MGH[1] Films taken at operation usually provided the best aid to classification of the fracture (CARLQUIST, 1947) The ten cases of fracture in radiographically apparent lesions found in this series were not classified in detail In 1 106 of the remaining 1,114 fractures anatomical classification of fracture type was made upon films of good quality Eight cases were classified by means of films of poorer quality or reports only Follow up examinations were made in Series A only

Series B Material from the 3 year period 1959—1961 was composed of 540 fractures in 535 patients All films of this series were evaluated by the author using the criteria applied to series A but fractures were classified only into cervical and trochanteric groups Nine fractures in radiographically apparent lesions were found

Of the 1 664 fracture cases found during the 13 year period covered by Series A and B 54 (46 female and 8 male) were second fractures during

[1] Dr B Frost Radiodiagnostic Department (Head Professor S Welin) Malmo General Hospital

this period and 38 (31 female and 7 male) were in patients who had had a cervical or trochanteric fracture before 1949 Two of the latter group sustained two fractures during the period of study

2 *Follow up of Probands in Series A*

Parish records as well as tax records in Malmo and elsewhere were consulted to identify those alive on July 1, 1960 (567 patients, 582 fractures) and determine the date of death of those deceased before July 1, 1960 (529 patients 537 fractures)

Information about 3 patients was secured from relatives One patient was untraceable and one had left Sweden and could not be traced

All traced living probands of Series A were given an appointment for a clinical examination in the Orthopaedic Clinic at MGH Those who could not come to the clinic were examined in their homes or at the institutions where they lived Examinations were performed by the author or *one of three specially instructed medical students* 529 *patients* (543 fractures) of Series A were interviewed and examined in this way

Probands who declined examination or who had moved from Malmö were sent a questionnaire (22 patients), or were interviewed by telephone (6 patients) Two mentally deteriorated patients admitted to institutions outside Malmö were not examined Eight patients refused to cooperate

The purpose of the interview was to collect information on previous or later fractures, the number of childbirths, and the age at menopause, and to check the reliability of available case records with regard to previous diseases The result of the clinical after examination will be reported elsewhere

3 *Medical Records of Probands*

Series A The *main sources of information were case records of the* Orthopaedic Clinic of MGH Further information was taken from records of other clinics or institutions where the patients had received treatment before or after their fractures In about 500 cases one or more such records were studied and data about previous disease or fracture, number of children and treatment of the fracture were collected In 44 female and 16 male patients the medical history before the fracture was regarded as incomplete, and in 12 women and 2 men the case records of the fracture episode itself were inadequate

Series B Records of the Orthopaedic Clinic of MGH and other clinics were examined to collect data about type of injury, number of births age at menopause blood group and coexisting disease

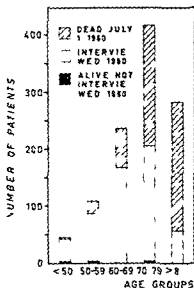


Fig 1
Age distribution of patients in series A interviewed and not interviewed in 1960 and dead before July 1 1960 Age at first fracture is indicated Two patients had not been traced

4 *Sources of Error in Identification and Follow up of Probands*

The film archives of MGH MMH and GH were the primary sources used for the collection of the cases To rule out possible mistakes in the registration of radiographs ward records and operating room records at the Orthopaedic Clinic were also examined

During part of the period of investigation films of deceased patients were discarded from the archives at MMH By reviewing case records of all patients with missing radiographs who had had pelvis hip or femur examined radiologically at MMH this source of error was avoided Two cases were discovered in this way

Patients residing in Malmo who had not been radiographed or treated there were not included in the material The insurance rules governing hospital care in Sweden render it extremely unlikely that patients normally resident in Malmo would be treated entirely in other centres In Series A there were two such cases discovered at re examination of known fractures

While it is rare that a fracture of the proximal end of the femur fails to be radiographed this could occur if the patient died soon after the fracture occurred or if the fracture were stable and the pain so moderate that the patient did not seek medical advice SPOTOFT (1944) believed this last alternative to be more common than is generally recognized If this were the case several such patients should have sought advice because of pain related to avascular necrosis In Series A 16 patients (1 5 per cent of the total material) with stable fracture were first diagnosed more than two weeks after the fracture incident

Table 2 *Incidence of some coexisting diseases in Series A and B*

	Series A	Per cent	Series B	Per cent
Rheumatoid arthritis	68/1 100	6 2	39/521	7 5
Diabetes mellitus	54/1 100	4 9	24/521	4 6
Hemiplegia	47/1 100	4 3	17/521	3 3

In older age groups a lower proportion of patients were available for examination due to the higher death rates of these groups (Fig 1) The percentages of patients in various age groups alive in 1960 were as follows under 50 years 96 per cent 50—59 80 per cent 60—69, 71 per cent 70—79 49 per cent over 80 20 per cent

If interviews of the probands disclosed facts about disease unrecorded in case histories, the age distribution of the survivors could introduce a bias affecting any study of the impact of previous disease upon the etiology of fracture For example fractures of the distal end of the forearm were more commonly reported in those re interviewed than in the total series Concerning other previous diseases or conditions few cases unrecorded in the case histories were disclosed at re interview Thus, e g , one patient with rheumatoid arthritis and one patient with diabetes mellitus were found To check the reliability of case records of Series A the incidence of some coexisting diseases in Series A was also compared with their incidence in Series B This comparison showed no significant difference with regard to the incidence of these coexisting diseases (Table 2)

D EVALUATION OF TRAUMA

1 *Degree of Trauma*

In studies of fracture of the forearm (ALFFRAM and BAUER, 1962) and of the tibial shaft (BAUER et al , 1962) the degree of violence causing a fracture was assessed according to available anamnestic data Fractures could be divided into two groups associated with moderate or severe trauma and this classification permitted resolution of the material into groups which were characterized also by age and sex distribution and type of fracture

Therefore the data in the present study were subjected to classification according to the following definitions

Moderate trauma — was defined as that resulting from violence equivalent to or less than a fall to the ground from the standing position Thus trauma resulting from a fall from a chair or bed was regarded as moderate A few

cases in which injury of any sort was denied have been included in this group They were however, subjected to more detailed analysis

Severe trauma — was defined as that resulting from violence more severe than a fall from the standing position such as a fall from standing upon a chair or a table, a fall on a stairway and all traffic accidents

2 *Sources of Error in Evaluation of Trauma*

Information about the accident was collected only from the case records because it was believed that probands' recollection immediately following the injury would be more accurate than at the time of reexamination It is evident that overlaps exist between the two groups in the classification adopted Some traffic injuries for example a pedestrian being knocked down by a bicycle might have resulted in relatively mild trauma On the other hand the forces involved in falls to the ground depend upon such factors as surface the efficiency of reflex mechanisms, and whether there was direct violence to the hip region BACKMAN (1957) calculated the force of impact of a fall on the hip to be as much as ten times the body weight There is little question however, that trauma resulting from falls from a height is still more severe

E DEFINITIONS AND STATISTICS[1]

The terms used in the present study were defined as follows

Fracture case Each separate fracture of the proximal end of the femur A patient who sustained two fractures was regarded as two fracture cases

Patient or Proband A person sustaining one or more such fractures during the period studied

Age Age at last birthday

Age and Sex Incidence The annual number of fracture cases per 1,000 inhabitants per sex and age group Age groups were generally five year age groups Calculations were based upon the mean population during the periods 1951—1960 1951—1955, or 1956—1960

Age Specific Sex Ratio Ratio of age and sex incidences

Standardized Morbidity Rates The age and sex incidence during a given period projected upon the population of Malmo in 1960

[1] Data treated statistically under supervision of Professor C F Quensel Institute of Statistics University of Lund

Standard statistical methods have been used. Differences were regarded to be

highly significant (***) when $P<0.001$
significant (**) when $0.001<P<0.01$, and
probably significant (*) when $0.01<P<0.05$.

In the study of frequencies of e. g. second fractures of the proximal end of the femur the difference between the observed number (0) and the excepted number (E) was compared with the standard deviation of the observed number which equals $\sqrt{E}$. When the difference was $2\sqrt{E}$ or more it was said to be significant ($P<0.05$). No more detailed statistical analysis was carried out in such comparisons.

F. PRIMARY TREATMENT OF FRACTURES IN SERIES A

An analysis of the initial treatment of cervical and trochanteric fractures is given here by a survey of the principles followed in Series A (Table 3).

1. *Cervical fractures*

Non-impacted fractures were nailed with a three-flanged Johansson nail or multiple Nyström nails. Reduction and internal fixation were controlled radiographically. General anesthesia was almost always employed. During the period under study 91 per cent of all non-impacted cervical fractures primarily treated at MGH, MMH and GH were operated upon. The incidence of operation was almost constant during each year of the period of study. The interval between fracture and operation varied greatly depending upon the general condition of the patient. The mean interval was 4 days, with 75 per cent of the cases being operated within one week of the accident.

Forty-one patients with non-impacted fractures primarily treated at MGH, MMH and GH did not undergo operation. Thirty-six of these were in such poor general condition that operation was felt to be contraindicated and 27 of these died within three months of injury. Two patients refused operation, one of whom was treated in a hip spica. In 3 cases the reason for non-operative treatment could not be deduced. Four patients were treated conservatively by private physicians in Malmö, but were radiographed at MGH or GH. Six patients received initial operative treatment in other centres.

Table 3 *Type of primary treatment in Series 1*

Fracture types	Conservative				Operative			
	Non weight bearing	Traction	Plaster	Not known	Nailing procedures S Johansson[1]	Nystrom[2]	McLaughlin	Other methods
Cervical non impacted	[illegible]0	19	1	4	398	30	2	1
Cervical impacted	109	87	0	6	24	9	0	0
Trochanteric	32	304	0	4	1	1	50	12

[1] S Johansson (1934)
[2] Nystrom (1938)

Table 4 *Sex distribution of cervical fractures in Series 1 grouped according to anatomical type and stability*

	Subcapital fractures				Transcervical fractures				Not classifiable fractures				Total cervical fractures
	Unstable	Stable	Unknown	Total	Unstable	Stable	Unknown	Total	Unstable	Stable	Unknown	Total	
Women	286	1[illegible]1	[illegible]6	433	105	2[illegible]	9	136	4	2	—	6	57[illegible]
Men	42	18	3	63	47	21	2	70	2	—	—	2	135
Total	3[illegible]8	139	29	496	152	43	11	206	6	2	—	8	710

Impacted fractures were usually treated conservatively All impacted fracture cases in Series A were treated at MGH MMH or GH Thirty three of these cases were nailed (14 per cent) The frequency of operation in this group was higher during the last three years of the study than during the earlier years of the period (27 and 4 3 per cent, respectively) Twenty four impacted fractures were operated upon primarily In 14 of these there was evident angulation and in 5 there was doubt about the stability of the fracture In 2 patients with stable fractures in good position operation was performed to shorten the period of immobilization In 3 cases the reason for operation could not be deduced

The remaining 9 cases were operated because of loss of position of the fractures after a period of conservative treatment

Endoprosthetic replacement of the femoral head was not done as a primary procedure in Series A

2 *Trochanteric Fractures*

Trochanteric fractures in Series A were usually treated conservatively Internal fixation was used in only 16 per cent of the cases Operative treatment was more common during the last two years of the period than during the earlier years (33 per cent and 7 5 per cent respectively) Of 8 patients with trochanteric fractures treated outside Malmo, 4 were operated and 4 had conservative treatment

III RESULTS

A RADIOGRAPHICALLY APPARENT LESIONS OF THE PROXIMAL END OF THE FEMUR

Skeletal lesions due to primary and secondary tumours other tumorous or cystic destructive processes as well as osteogenesis imperfecta and Paget s disease are obvious factors predisposing to fracture These fractures have been excluded from the present study but will be considered in the General Discussion

In the total material of 1 664 fracture cases 19 such fractures were found (Table 5) in 2 of which the exact nature of the lesions was not known Moderate trauma was recorded in 8 cases and severe trauma in 2 cases The remaining 9 were spontaneous fractures The average age at fracture was 61 5 years

B TYPES OF FRACTURE

1 *Main Anatomical Types*

PREVIOUS STUDIES

Remarkable differences exist in the proportions of cervical versus trochanteric fractures in series reported in the literature Data from some representative series are shown in Table 6 A majority of authors recorded a predominance of cervical fractures ranging from 57 to 69 per cent On the other hand WATSON JONES (1955) observed that trochanteric fractures 'occur in elderly patients even more frequently than fractures of the femoral neck itself' STEWART (1955) FITTS JR et al (1959) and MANPFL et al (1961) also found a predominance of trochanteric fractures as did the British Committee for Fractures in the Elderly (personal communication) In IBSEN s material (1951) it was calculated that trochanteric fractures were more common than cervical fractures above the age of 80, in contrast to the situation below that age

In LOFBERG s series from Malmo (1924) 34 per cent of female and 46 per cent of male fracture cases were trochanteric STEWART (1955) found that 52 per cent of female and 72 per cent of male patients had trochanteric fractures It appears that trochanteric fractures are more common in males than in females

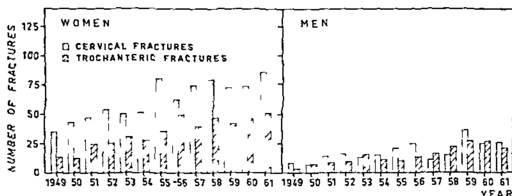


Fig 2
Fractures in erie A and B grouped according to ex type and year

Table 7 *Fractures in 1949—1953 1954—1958 and 1959—1961 grouped according to sex and type*

Period	Women		Men		Total	
	Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures
1949—1953	229 (69)	104	53 (59)	37	282 (67)	141
1954—1958	346 (64)	196	82 (55)	67	428 (62)	263
1959—1961	230 (63)	136	84 (54)	72	314 (60)	208
Total	805 (65)	436	219 (55)	176	1 024 (63)	612

Bracketed figures denote per cent

2 Types of Cervical Fractures

a Anatomical types

PREVIOUS STUDIES

Although anatomical classifications have been widely used there have been few reports of relative incidence of different types of fracture In 105 cervical fractures FALTIN (1924) found 71 per cent were subcapital, while HULTH (1956) found 55 subcapital fractures in 100 cervical cases MANSFEL et al (1961) found 26 per cent subcapital fractures in 196 cases but did not define their method of classification None of these authors divided their series according to age or sex

PRESENT STUDY

In Series A 70 per cent of all cervical fractures were subcapital (Table 4 page 21) Subcapital fractures were more common in women (75 per cent) than in men (47 per cent)(***)

b *Impaction and Stability*

PREVIOUS STUDIES

Reports of the relative incidence of impacted (or valgus) fractures gave values ranging from 10 to 23 per cent of all cervical fractures (Table 6). It was often difficult to know whether or not these figures included fractures which displaced during conservative treatment. CRAWFORD (1960) reported 8 per cent and FLATMARK and LONE (1962) 7.5 per cent of displaced fractures.

PRESENT STUDY

At the time of admission 235 of the 710 cervical fractures (33 per cent) in Series A were judged to be impacted. For various reasons (immediate internal fixation of the fracture or lack of radiographic control) the degree of stability could not be evaluated in 40 of these cases. Eleven cases displaced during conservative treatment (5.6 per cent of the conservatively treated and radiographically controlled impacted cervical fractures).

The remaining 184 impacted fractures (26 per cent of all cervical fractures) remained stable. Seventy five per cent of the stable cervical fractures were subcapital, 24 per cent transcervical, and 1.1 per cent could not be classified as to anatomical type. In unstable fractures the corresponding percentages were 67, 31 and 1.2 respectively. Stability was more common(*) in subcapital fractures (30 per cent) than in transcervical fractures (22 per cent) (Table 4).

Impacted fractures were equally common in men and women.

Among impacted fracture cases 92 patients gave a history of weight bearing on the injured leg after the probable time of fracture. Thirty two of these had been able to walk quite a distance. 75 patients reported they were unable to bear weight after the accident. In 68 case histories there was no information about weight bearing.

Fracture displacement under conservative treatment occurred in 4 patients who had given a history of weight bearing prior to admission, a frequency similar to that of displacement occurring in all conservatively treated impacted cervical fractures.

The time interval between fracture and displacement ranged from 8 to 77 days with a mean of 32 days. In one patient who had received radiotherapy for cancer of the ovary the displacement was not noted until 190 days after the probable date of fracture. This gradual development of fracture following radiotherapy is now a recognized syndrome.

COMMENTS

The ratio of cervical to trochanteric fractures in this material was in agreement with that reported in several series but was in contrast to that of other materials Several authors have reported a higher mean age in trochanteric fracture cases than in cervical fracture cases This observation was also made in the material

Differences in the age composition of the population from which the reported materials were drawn as well as selection of any kind may affect the distribution of fracture types As the older age groups constitute a steadily increasing proportion of the population in most Western countries, and trochanteric fractures occur in patients of higher average age than do cervical fractures an increase in the proportion of trochanteric fractures is to be expected in this material

The distribution of subcapital and transcervical fractures in this series agreed with the findings of FALTIN (1924) and HULTH (1950) but contrasted with figures given by MANPEL et al (1961) probably because of differences in definitions or selection of the population

It was evident in this series that a sex linked difference exists in the prevalence of the anatomical types of cervical fracture In women sub capital fractures were three times more common than transcervical frac tures In men the two types were about equally common The transcervical fracture seems to be a male fracture type This may indicate the presence of some biologic or traumatic factor BACKMAN (1957) found the results of experimental studies suggested that subcapital fractures occur only in association with reduced skeletal strength This supports the idea that biologic factors partly determine the type of fracture

The incidence of cervical fractures impacted at the time of initial examination (33 per cent) was higher in this material than has been reported in other series (Table 6) It is likely that this was due to differences in methods of classification

Twenty six per cent of all cervical fractures (84 per cent of those im pacted) remained stable and did not require internal fixation This figure is higher than that given in most reports but is in agreement with ENDER (1952)

In contrast to the marked sex difference found in the incidence of ana tomical types of cervical fracture no sex difference was observed in the incidence of impaction or stability

SUMMARY

Cervical fractures were more common than trochanteric fractures in the total series and in women In men they were about equally

common Trochanteric fracture have apparently become more common due to changes in the age distribution of the population

Three out of 4 cervical fractures in women were subcapital while in men subcapital and transcervical fractures were equally common

One of every 3 cervical fractures was initially judged to be impacted and 1 out of every 4 cervical fractures remained stable

The occurrence of impaction or stability was unrelated to sex

C SEX AND AGE DISTRIBUTION

PREVIOUS STUDIES

It has long been recognized that fracture of the proximal end of the femur occurs predominantly in women (COOPER 1824 BRUNS 1882) The female male sex ratio ranges from 2 6 to 4 0 in unselected series of such fractures (Table 6)

The sex ratio has been reported to be higher in cervical than in trochanteric fracture (JOHANSSON 1934 NYSTROM 1938 ODEN 1947 IB EN 1951 STEWART 1955) This female predominance has been observed to increase with age in both types of fractures (BRUNS 1882 NYSTROM 1938 DUHAMEL, 1947) Of those quoted above only BRUNS (1882) tried to relate the sex ratio of fracture cases to that of the population at risk In his series fractures below 50 years of age were six times more common in men while above that age such fractures were two and one half times more common in women

The average age of unselected series of cervical and trochanteric fracture patients in the literature ranges from 70 to 76 years (Table 6)

Most authors state that patients with trochanteric fractures have a higher mean age than patients with cervical fracture (LINDGREN 1924 CLEVELAND et al 1951 CONWELL and REYNOLDS 1961) but Stewart (1955) and CHRISTIANSEN (1958) found no such age difference MCELVENNY (1957) pointed out that while subcapital fracture were uncommon below the age of 60 they became increasingly common above that age LINTON (1944) noted that the average age of abduction fracture cases was lower than the average age of adduction fracture cases

PRESENT STUDY

Seventy nine per cent of *cervical fractures* occurred in women a female male sex ratio of 3 8 (Table 7) As there were more women than men in the population of Malmö and this predominance increased with age the age specific sex ratio (page 19) is a more valid measure of the relative sex incidence of these fractures The age specific sex ratio of cervical fracture during the period 1951—1960 was 2 7

Table 8 *Cervical fractures in Series A grouped according to age sex and anatomical type*

Age groups	Women			Men		
	Sub capital	Trans cervical	Unclas i fiable	Sub capital	Trans cervical	Unclas i fiable
<60	57	19	2	8	21	—
60—69	104	36	2	16	14	—
70—79	156	54	2	24	23	2
>80	116	27	—	12	12	—
Total	433	136	6	63	70	2

Table 9 *Ages of patients at time of fracture grouped according to type and sex*

Type of fracture	Women			Men		
	No of ca es	Mean	Error of mean	No of ca es	Mean	Error of mean
Cervical (A+B)	805	71 7	0 38	219	68 6	0 95
Trochanteric (A+B)	436	75 2	0 52	176	69 4	1 12
Total (A+B)	1 241	73 0	0 33	395	69 0	0 70
Cervical (A)						
Unstable	395	72 5	0 51	91	69 8	1 33
Stable	141	69 1	1 01	39	63 5	2 75
Subcapital	433	72 3	0 53	63	70 7	1 48
Unstable	286	73 1	0 59	42	69 7	1 91
Stable	117	69 4	1 16	18	72 3	2 17
Transcervical	136	70 7	0 92	70	65 4	1 98
Un table	105	71 2	1 02	47	69 7	1 93
Stable	22	68 1	2 43	21	55 9	4 19

In cervical fracture case , 25 per cent of the women and 20 per cent of the men were over 80 years of age and 61 and 58 per cent respectively over 70 years of age (Fig 3) Fifteen per cent of women and 22 per cent of men were below age 60 indicating a shift toward males in younger age groups The mean age at fracture was lower(**) in men than in women (68 6 ± 0 95 and 71 7 ± 0 38 years respectively)

In women of Series A, there was no correlation between age and the anatomical type of cervical fracture However the ratio of subcapital to transcervical fracture was 4 3 in females above age 80 compared to a ratio of 2 9 in females below this age (Table 8)

In men above 60 years of age the anatomical types of cervical fracture were equally common below that age, however transcervical fractures prevailed(*)

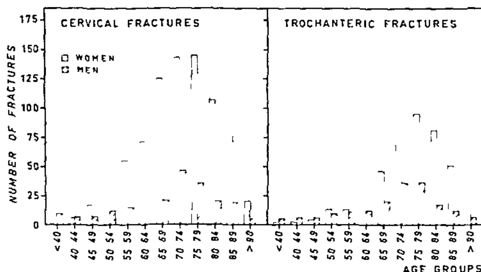


Fig 3
Fractures in series A and B grouped according to age sex and type

Table 10 *Cervical fractures in Series A grouped according to age sex and stability*

Age groups	Women			Men		
	Unstable	Stable	Unclassifiable	Unstable	Stable	Unclassifiable
<60	44	28	6	18	10	1
60—69	98	39	5	19	9	2
70—79	155	47	10	35	16	1
>80	98	31	14	19	4	1
Total	395	145	35	91	39	5

The average age at fracture for all anatomical types of fracture is given in Table 9 In both sexes subcapital fracture occurred at a somewhat higher average age than transcervical fracture This difference was significant(*) in men but not in women

Stable fractures in Series A showed an increase in younger age groups when compared with the age distribution of unstable fractures (Table 10) The average age of stable fracture cases was therefore lower than that of unstable cases in women(**) as well as in men(*)

The average age of patients with stable and unstable cervical fractures was not related to anatomical type of fracture In men, however the average age of stable transcervical fracture cases was lower(***) than that of stable subcapital fractures

Table 8 *Cervical fractures in Series A grouped according to age sex and anatomical type*

Age groups	Women			Men		
	Sub capital	Trans-cervical	Unclassifiable	Sub capital	Trans cervical	Unclassifiable
<60	57	19	2	8	21	—
60—69	104	36	2	16	14	—
70—79	156	54	2	27	23	2
>80	116	27	—	12	12	—
Total	433	136	6	63	70	2

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Trochanteric (A+B)	436	75 2	0 52	176	69 4	1 12
Total (A+B)	1 241	73 0	0 33	395	69 0	0 70
Cervical (A)						
Unstable	395	72 5	0 51	91	69 8	1 33
Stable	141	69 1	1 01	39	63 5	2 75
Subcapital	433	72 3	0 53	63	70 7	1 48
Unstable	286	73 1	0 59	42	69 7	1 91
Stable	117	69 4	1 16	18	72 3	2 17
Transcervical	136	70 7	0 92	70	65 4	1 98
Unstable	105	71 2	1 02	47	69 7	1 93
Stable	22	68 1	2 43	21	55 9	4 19

In cervical fracture cases, 25 per cent of the women and 20 per cent of the men were over 80 years of age, and 61 and 38 per cent, respectively over 70 years of age (Fig 3) Fifteen per cent of women and 22 per cent of men were below age 60 indicating a shift toward males in younger age groups The mean age at fracture was lower(**) in men than in women (68 6 ± 0 95 and 71 7 ± 0 38 years respectively)

In women of Series A, there was no correlation between age and the anatomical type of cervical fracture However the ratio of subcapital to transcervical fracture was 4 3 in females above age 80 compared to a ratio of 2 9 in females below this age (Table 8)

In men above 60 years of age the anatomical types of cervical fracture were equally common below that age, however transcervical fractures prevailed(*)

specific sex ratio of 2 1 In the present series the age specific sex ratio was 2 4 about the same as reported by BRUNS

The higher sex ratio in cervical than trochanteric fractures reported by several authors (JOHANSSON 1934 NYSTROM 1938 ODEN 1947 IBSEN, 1951 STEWART 1955) was confirmed in this series even after correction for age and might indicate a sex linked difference between the two types of fracture

The increase of the female predominance with age observed by some authors (BRUNS 1882 NYSTROM 1938 DUHAMEL 1947) could be only partly confirmed Below age 50 the proportion of female patients increased while above that age there was no marked change in the age specific sex ratio as shown in Figure 4

SUMMARY

Fractures of the proximal end of the femur were about two and one half times more common in women than in men after correction for the age of the population at risk The age specific sex ratio was higher in cervical than in trochanteric fractures There was no change in the age specific sex ratio after the age of 50

There was no definite difference in the incidence of subcapital or trans cervical fractures in different age groups in women In men below 60 transcervical fractures were more common than above that age

The average age of women with cervical fractures was significantly lower than that of women with trochanteric fractures In men there was no significant age difference

Patients with stable cervical fractures had a lower average age than patients with unstable fractures

D TYPES OF TRAUMA ASSOCIATED WITH FRACTURES

PREVIOUS STUDIES

COOPER (1824) noted that fractures of the neck of the femur were usually a result of moderate trauma He described two women who sustained fractures as a result of merely stumbling More than a hundred years later APFELBACH and ARIES (1936) stated that case histories often suggested a primary fracture due to a mis step or twist and that the fall was secondary to the fracture Whether the fracture is due to the fall or vice versa has since been a matter of conjecture CONWELL and REY NOLDS (1961) thought that in a majority of cases the fall was the result rather than the cause of the fracture MCELVENNY (1957) believed this to be a rather common sequence of events SMITH (1953) felt that while ex

ternal forces frequently are the cause of other fractures fractures of the neck of the femur are due to muscular forces, and reported two fracture cases occurring without a fall However the strength of the external rotators was estimated experimentally by BACKMAN (1957) who found that there was 'very little possibility of its producing fractures' and concluded that "a fall on the hip is the most plausible and natural cause of femoral neck fractures" There are few reports in the literature of definitely non traumatic cases of fracture of the proximal end of the femur, with the exception of march fractures in young adults (for references, see ERNST, 1963)

Some authors found a marked difference in the degree of injury reported by female patients in comparison with male patients While a majority of females gave a history of slight or moderate injury, males on the contrary, often reported severe injury as the cause of the fracture (PELS LEUSDEN, 1902 STEWART 1955) In experimental studies it was found that less force is generally required to cause fracture of female than of male bone specimens (MESSERER 1880 KOLODNY 1925 SPOTOFT 1944 FRANKEL, 1960)

The force required to cause fractures of the type under study is greater in young adults and in middle aged patients than in the aged (CAVE 1960 CONWELL and REYNOLDS, 1961 MÅRTENSSON 1962) This observation was also made by KOCHER (1896) in his experimental studies, but could not be definitely confirmed by BACKMAN (1957) STEWART (1955) found it 'significant that two female patients under 50 had had violent falls at work which none over 50 had In men, however major accidents are equally scattered over the normal life span"

PRESENT STUDY

Anamnestic data on the type of trauma sustained by the patients were available in 1,099 cases (99 per cent) of the 1 114 fracture cases in Series A According to the definition given on page 18 a classification of the violence involved was made in each case

1 *Moderate and Severe Trauma in Relation to Sex and Type of Fracture*

The fracture cases of Series A were divided into two groups associated with severe or moderate trauma as shown in Table 11, which also lists the more common mechanisms of injury

Of the 568 female and 131 male *cervical fracture* cases 191 women and 67 men (87 and 52 per cent respectively) suffered moderate trauma A further 14 women and 1 man denied any injury so that in 89 per cent of women and 53 per cent of men cervical fractures were associated with moderate or no trauma (***) (Table 11)

The distribution of degree of trauma was the same for subcapital and

Table 11 *Fractures in Series 1 grouped according to degree of trauma sex and main anatomical type*

	Women		Men		Total			
					Women		Men	
	Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures	No	Per cent	No	Per cent
Moderate or no trauma								
No trauma	14	—	1	—	14	1 6	1	0 4
Fall on ground	487	240	67	55	727	83	122	51
Fall out of bed or chair	4	14	—	1	18	2 6	1	0 4
Severe trauma								
Fall from a height	15	14	13	8	29	3 3	21	8 8
Fall on stairs	31	17	7	9	48	5 5	16	6 7
Pedestrian knocked down in traffic	8	8	3	4	16	1 8	7	[illegible] 9
On bicycle	8	2	33	22	10	1 1	55	23
On motor bicycle	—	—	3	4	—	—	7	3 0
In automobiles	1	1	1	—	2	0 2	1	0 4
Other severe trauma	—	—	3	1	—	—	4	1 7
No data available on trauma	7	4	4	—	11	1 3	4	1 7
Total	575	300	135	104	875		239	

Table 12 Relation between degree of trauma and anatomical type of fracture in Series A

Trauma	Women				Men			
	Sub capital	Trans cervical	Total cervical	Trochan teric	Sub capital	Trans cervical	Total cervical	Trochan teric
Moderate	379	120	505	254	35	32	68	56
Severe	49	14	63	42	25	37	63	48
Not known	5	2	7	4	3	1	4	—
Total	433	136	575	300	63	70	135	104

Seven fractures with moderate trauma and one fracture with severe trauma were unclassifiable as to anatomical type

transcervical fractures in women, while in men transcervical fractures were slightly more often associated with severe trauma In the total series subcapital fractures were more commonly seen(**) with moderate trauma than were transcervical fractures (Table 12) Stability in cervical fractures was unrelated to the degree of trauma

A similar pattern of trauma was observed in the 295 female and 104 male *trochanteric fractures* in which the mechanism of injury was known Moderate trauma was noted by 254 women and 56 men (86 and 56 per cent respectively) of this group(***) No patient denied injury at the time of fracture

The most common mechanism of moderate injury was a simple fall and of severe injury a fall on stairs in women (5 6 per cent), and traffic accidents in men (29 per cent) (Table 11)

Within each sex and within the main anatomical fracture types the proportion of moderate trauma to severe trauma was constant

2 *Moderate and Severe Trauma in Relation to Age at Fracture*

The relation between degree of trauma and age is shown for both sexes and types of fracture in Table 13 and Figure 5 Moderate trauma was predominant in females in all age groups for both cervical and trochanteric fractures In women severe trauma was more often seen under age 60 than above that age(*) this difference was significant only in trochanteric fractures(*)

In men a clear relation was observed with severe trauma predominant in both fracture types below age 70 and moderate trauma predominant above that age(***)

It was evident that there was a change in the pattern of trauma with age which was more pronounced in males

Table 13 *Age and sex distribution of fractures of the proximal end of femur in Series I classified according to degree of trauma and anatomical type*

	Women				Men			
	Moderate trauma		Severe trauma		Moderate trauma		Severe trauma	
Age groups	Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fracture
<60	64 (16)	18 (6)	13 (10)	8 (8)	5 (4)	6 (4)	22 (20)	15 (12)
60—69	126 (87)	44 (30)	15 (12)	5 (3)	13 (8)	6 (4)	17 (14)	12 (11)
70—79	187 (110)	96 (66)	21 (18)	22 (19)	33 (21)	21 (14)	17 (16)	19 (16)
>80	128 (109)	95 (79)	15 (13)	7 (7)	17 (14)	23 (21)	7 (7)	2 (1)
Total	505 (38[illegible])	253 (181)	63 (53)	42 (37)	68 (47)	56 (43)	63 (57)	48 (40)

Bracketed figures denote fractures in patients without predisposing factors

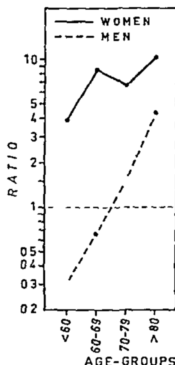


Fig 5
Ratios moderate severe trauma in series A grouped according to age and sex

3 *No Trauma*

Fifteen patients (14 women and 1 man) suffered fractures without a significant injury All of these were cervical (2 1 per cent of cervical fractures where degree of trauma was known) (Table 14)

Eleven of these were impacted subcapital two were subcapital non impacted and 2 were transcervical non impacted fractures

Eight patients had received radiotherapy for a pelvic malignancy In these ca es increasing local pain and a limp led to radiographic diagnosis of the fracture from 1 to 17 months after the onset of pain

The remaining 7 female patients included 3 with coexisting invalidism (rheumatoid arthritis severe osteoporosis and malunion of trochanteric fracture) and 4 who had no known coexisting disease This group of 7 cases noted sudden pain at the time of fracture although in two cases the diagno is was not established until 2 weeks later

4 *Traffic Accidents*

Fractures due to traffic accidents occurred in 28 women and 70 men (3 2 and 29 per cent) of cases of known type of injury Motor vehicles were involved in 11 female and 19 male cases (1 3 and 8 0 per cent) Only 3 patients were pas engers in cars (Table 11)

Although the annual number of casualties in road accidents in Sweden more than doubled over the period of this study the proportion of fractures

Table 14 *Fractures not preceded by any trauma in Series I*

Code No	Sex	Age	Fracture type	Onset of symptoms	Interval between onset of symptoms and diagnosis	Predisposing factors
158	M	67	SC impacted	gradual	6 months	radiotherapy
578	W	62	SC impacted	gradual	3 months	radiotherapy
696	W	74	TC non impacted	gradual	2 months	radiotherapy
819	W	72	SC impacted	gradual	12 months	radiotherapy
877	W	62	SC impacted	gradual	15 months	radiotherapy
944	W	63	SC impacted	gradual	1 month	radiotherapy
996	W	56	SC impacted	gradual	4 months	radiotherapy
997	W	57	SC impacted	gradual	17 month	radiotherapy + rheumatoid arthritis
908	W	62	SC impacted	sudden	2 weeks	rheumatoid arthritis
309	W	86	SC impacted	sudden	[illegible] weeks	severe osteoporosis
305	W	90	TC non impacted	sudden	none	malunion of trochanteric fracture same side
284	W	83	SC impacted	sudden	none	
749	W	71	SC non impacted	sudden	none	
745	W	72	SC impacted	sudden	none	
98	W	57	SC non impacted	sudden	none	

SC = subcapital and TC = transcervical

in this material due to traffic accidents remained nearly constant (9.6 per cent in 1949—1953 8.5 per cent in 1954—1958 and 8.7 per cent in 1959—1961) (Statistical abstract of Sweden, 1960)

Among female cases cyclists and pedestrians were equally common but in male cases cyclists were 8 times as common as pedestrians

COMMENTS

It has been stated that fractures of the proximal end of the femur, particularly cervical fractures often occur without significant injury Such a history was recorded in only 15 patients (1.4 per cent) in the total material In 11 of these some coexisting disease probably predisposed to fracture It was also significant that almost half of the fractures in radiographically apparent lesions (Table 5) appeared spontaneously The small proportion of spontaneous fractures recorded in the series supported the view that fracture of the proximal end of the femur almost always occurs in association with trauma

The change in distribution of type of trauma with age noted by others was found in this material While STEWART (1955) observed the frequency of major accidents to be independent of age in men in this material the change in distribution of type of trauma with age was pronounced in men

The pattern of trauma in cervical fractures was similar to that found in trochanteric fractures in contrast to the observation of MORRIS (1941) NEWELL (1947) BOYD and GRIFFIN (1949) and BICK (1960)

SUMMARY

In women 9 out of 10 fractures were associated with moderate or no trauma In men severe trauma dominated below age 70 and moderate trauma in older age groups The increase in the proportion of moderate trauma with age was more pronounced in men than in women

The pattern of type of trauma was similar in cervical and trochanteric fractures After moderate trauma subcapital fractures were more common than transcervical fractures Recorded degree of trauma was not related to the stability of cervical fractures

Eleven of 15 spontaneous fractures were in patients with diseases predisposing to fractures

Fractures due to traffic accidents were uncommon in women but accounted for 29 per cent of the cases in men

E MORTALITY

PREVIOUS STUDIES

In most reports mortality refers to hospital mortality i e number of deaths occurring in hospital (RENO and BURLINGTON 1958

FAHEY 1949, SCHENK JR et al 1956 CARLQUIST 1947 FINNEY et al 1959 MANPEL et al 1961 JENSENIUS 1956) *Because length of hospital* stay and hence mortality is influenced by administrative as well as other factors (IBSEN 1951) comparisons of such materials are difficult (SPOTOFT 1944) FITTS JR et al (1959) used mortality within 6 months of fracture or until weight bearing was resumed as a criterion LINTON (1944) BOYD and GEORGE (1947) and BOYD and GRIFFIN (1949) gave figures for the mortality within 3 and 6 month of fracture

A majority of deaths occur within the first few weeks after fracture (BOYD and GEORGE 1947 KENNEDY et al 1957 FITTS JR et al 1959 MANPEL et al 1961) FITTS JR et al (1959) found that life expectancy in fracture patients surviving 6 months was not appreciably less than that of the general population

A higher mortality has been reported in patients with trochanteric than with cervical fracture (LINDGREN 1924 NEWELL, 1947 BOYD and GRIFFIN 1949 CLEVELAND et al 1951 IBSEN 1951 WEDEEN et al 1957 FITTS JR et al 1959 MCGOEY and EVANS 1960) while others have been unable to confirm this (RENO and BURLINGTON 1958 MANPEL et al 1961)

Mortality of patients with fractures of the proximal end of the femur particularly trochanteric fracture has been reported higher in conservatively treated than operated cases (CLEVELAND et al 1947 NEWELL, 1947 CARLQUIST 1947 BICKEL and JACKSON, 1950 BEEGEL, 1958 BANKS and QUIGLEY 1960 MCGOEY and EVANS 1960) Others have reported mortality equal in these groups (IBSEN 1951, SCOTT 1951 STOREN 1956 SCHENK JR et al 1956) KENNEDY et al (1957) pointed out that the age and general condition of patients were of more importance with regard to mortality than were type of fracture or methods of treatment

NEWELL (1947) felt the higher mortality in patients with trochanteric fractures was partly related to their higher mean age and partly to a higher incidence of severe trauma in this group

PRESENT STUDY

1 *Mortality of fracture patients compared with the general population*

The mortality of the patients in Series A at intervals following the fracture was determined as described on page 16 (Fig 6) and the prognosis quod vitam calculated using the method described by BERKSON and GAGE (1950) and used by HALL (1961) Figure 6 shows clearly that a majority of deaths occurred in the first 2 to 3 months following the fracture

These observed post fracture survival rates were compared with survival rates based upon the life table of Sweden adjusted to the age and sex

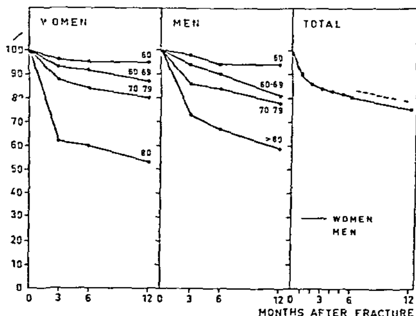


Fig 6
Surv ival rates 3 6 and 12 month after fracture in eries A grouped according to age and sex

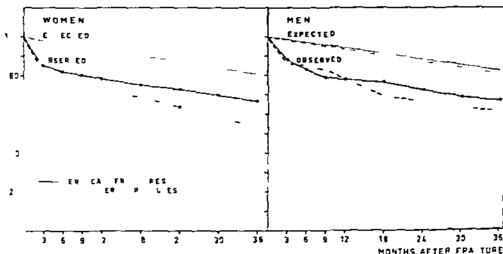


Fig 7
Observed survival rates in eries A grouped according to age sex and fracture type compared with expected survival rates of Swedish people of corresponding age and sex.

of the fracture patients assuming that the life expectancy of women and men in Malmo was the same as that of women and men of equal age in the total population of Sweden

This comparison of observed and expected survival rates showed that after the initial three months following the fracture survival rates of fracture patients irrespective of age sex or anatomical type of fracture were similar to those of the general population (Fig 7)

2 *Mortality in relation to age sex and type of fracture*

Figure 6 shows the relationship between age and survival rate in ten year age groups for men and women illustrating the importance of knowing the age distribution of materials when comparisons of total mortality are being made

To study the relation of type of fracture and sex to mortality in patients in Series A the following method was used Assuming there was no difference in mortality between the two main fracture types the proportions of patients with cervical and with trochanteric fractures dead within 3 and 6 months were calculated for each sex and age group These figures were multiplied by the observed number of patients in the corresponding age group giving the *total number of expected deaths* for each sex and type of fracture After correction for difference in the age distribution of the patients mortality was found to be unrelated to sex or to the main type of fracture (Table 15)

3 *Mortality in relation to treatment*

This material was not entirely suitable for study of the relation of mortality to method of treatment since selection of patients for operative or conservative treatment may have been based upon factors which greatly influence mortality In several cases operation was regarded as contra indicated because of the patients' poor general condition In other cases operation was done to shorten the period of immobilization of such patients

Since it was found that mortality was not related to sex or type of fracture in Series A a comparison of mortality in patients with non impacted cervical fractures operated upon in 91 per cent of cases and trochanteric fractures operated upon in 16 per cent of cases would give information about the effect of treatment on the three month mortality Assuming that there was no difference in mortality between the two series the expected number of deaths in non impacted cervical and in trochanteric fracture cases was calculated A comparison between observed and expected values (Table 16) indicates that the type of treatment did not influence the three month mortality

There was no change in mortality rate during the period under study

Table 15 *Observed and expected number of deaths within 3 and 6 months of fracture in Series A according to sex and type of fracture*

Age groups	No. of fractures: Cervical fractures, Women	Cervical fractures, Men	Trochanteric fractures, Women	Trochanteric fractures, Men	No. of deaths within 3 and 6 months: Cervical fractures, Women, 3 months	Cervical, Women, 6 months	Cervical, Men, 3 months	Cervical, Men, 6 months	Trochanteric fractures, Women, 3 months	Trochanteric, Women, 6 months	Trochanteric, Men, 3 months	Trochanteric, Men, 6 months
<50	17	14	6	8	0	0	0	1	0	1	0	0
50–54	23	8	9	4	0	0	0	1	1	1	0	0
55–59	38	7	12	9	3	3	0	0	0	0	1	1
60–64	57	16	17	6	4	4	1	1	0	0	0	0
65–69	8[illegible]	14	33	12	6	9	2	3	3	1	0	1
70–74	110	31	[illegible]6	2[illegible]	13	16	4	4	[illegible]	8	2	2
75–79	102	21	62	15	1[illegible]	18	4	6	8	11	3	3
80	113	[illegible]4	105	2	15	[illegible]3	5	7	36	16	8	9
Total	[illegible]7[illegible]	135	300	104	86	103	16	23	56	70	14	16
Percent					15	18	12	17	19	23	13	15
Expected No. of deaths assuming no difference in mortality with type of fracture					88	106	16	21	54	67	14	18
Expected No. of deaths assuming no difference in mortality with sex					8[illegible]	105	17	21	55	67	15	19

Table 16 *Observed and expected number of deaths within 3 months of non impacted cervical or trochanteric fractures in Series A*

Age groups	No of fractures		No of death	
	Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures
<50	12	14	0	0
50—54	2[illegible]	13	0	1
55—59	25	21	2	1
60—64	46	23	4	0
65—69	70	45	8	3
70—74	91	81	14	10
75—79	94	7[illegible]	15	11
>80	115	130	36	44
Total	475	404	79	70
Expected No of deaths assuming no difference in mortality with type of treatment			76	73

Table 17 *Observed and expected number of deaths within 3 months of fracture in Series A according to sex and degree of trauma*

Age groups	No of fractures				No of death			
	Moderate trauma		Severe trauma		Moderate trauma		Severe trauma	
	Women	Men	Women	Men	Women	Men	Women	Men
<50	18	9	3	12	0	0	0	0
50—54	24	0	8	11	1	0	0	0
55—59	41	2	9	14	3	0	0	1
60—64	6[illegible]	7	11	15	4	1	0	0
65—69	108	12	9	14	9	1	0	1
70—74	147	8	17	26	19	6	1	0
75—79	136	6	25	10	20	[illegible]	2	0
>80	223	40	[illegible]3	9	74	11	6	2
Total	759	124	105	111	130	26	9	4
Expected No of deaths assuming no difference in mortality with type of trauma					1[illegible]4	20	15	10

Three women dead within 3 months of fracture excluded because type of trauma not known

4 *Mortality in relation to type of trauma*

The type of injury was known in 1 099 cases in Series A The resulting trauma was classified as moderate in 883 cases and as severe in 216 cases The three month mortality in the former group was 18 per cent and in the

latter group 6 0 per cent When adjusted for differences in age 25 deaths were expected in the severe trauma group and 13 were observed (Table 17) One hundred forty four deaths were expected in the moderate trauma group and 156 were observed The three month mortality was significantly lower(***) after severe than after moderate trauma

COMMENTS

The mortality rates in this study 3 and 6 months following fracture were similar to a majority of corresponding figures in the literature (Table 6) BOYD and GEORGE (1947) reported mortality of 9 3 per cent within 6 months but did not state the average age of the patients The relation between mortality and age of the patients stressed by several authors (ODEN, 1947, IBSEN, 1951 WEDEEN et al 1957, KENNEDY et al 1957 RENO and BURLINGTON 1958) was demonstrated in this material

FITTS JR et al (1959) found that survival rates of fracture patients living for 6 months after injury were the same as those of the general population In this study it was found that as early as 3 months following the fracture the survival rates of the patients had become equal to those of the general population of Sweden

The difference in mortality between patients with cervical and trochanteric fractures often reported in the literature was not confirmed The observed differences are probably related to differences in the age composition of the series studied or length of interval between fracture and death, or possibly both factors

In agreement with some authors, but not with others, no difference in mortality was found between conservatively treated and operated cases The reduction in mortality of operated trochanteric fracture patients often reported may be due to selection patients in poor general condition are conservatively treated more often than healthy patients (SCOTT 1951) Another factor tending to reduce the reported mortality of operated cases is their shorter period of hospital care (SCHENK JR et al 1956 CLEVELAND et al 1959)

NEWELL (1947) believed severe trauma was associated with increased mortality In this series after adjusting for age differences, mortality following severe trauma was significantly lower than following moderate trauma suggesting that the severe trauma may be sustained by healthier patients

SUMMARY

Mortality within three months of fracture was related to the age of the patient at the time of fracture but was not related to sex, type

of fracture or method of treatment A higher mortality rate was found following moderate trauma indicating that fractures caused by severe trauma occur more often in relatively healthy individuals

F FRACTURE INCIDENCE

1 *Age and Sex Incidence*

To calculate the frequency of fractures and to compare data about fracture incidence in different populations it is necessary to consider the age and sex composition of the population from which the material is drawn The age and sex incidence as defined on page 19, is a suitable standard of comparison

PREVIOUS STUDIES

BRUNS (1882) attempted to correlate numbers of different kinds of fracture collected from a large group of German hospitals with the population of Germany In this way he obtained information about the age and sex distribution of the material but not fracture incidence STEWART (1955 1958) related the number of fractures of the proximal end of the femur occurring during a certain period in the district of Dundee in Scotland to census data from the same area and for the first time calculated the incidence of this fracture in women BUHR and COOKE (1959) projected fractures treated in the Radcliffe Infirmary in Oxford from 1953 to 1957 upon the population of England and Wales to study general age and sex patterns of fracture MÅRTENSSON (1962) has made a similar study in Goteborg Sweden The Committee for Fractures in the Elderly in Great Britain (personal communication) also performed a study in Oxford and Dundee collecting data on cervical and trochanteric fractures which occurred during the five year period 1954—1958

All of these investigations showed that the age and sex incidence of fracture of the proximal end of the femur is higher in women than in men and increases steadily with advancing age in both sexes (Fig 8)

COMMENTS

Standardized morbidity rates calculated from the fracture incidence in 1955—1959 in Malmö were 126 7 for women and 39 8 for men, and in Göteborg 146 3 for women and 34 0 for men The e figures agreed closely, the standardized morbidity rate in women being a little higher in Göteborg than in Malmö

Standardized morbidity rates in both sexes in Dundee and in Oxford were similar (Table 19) but were significantly lower ($P < 0\ 05$) than standardized morbidity rates in Malmö and Göteborg The fracture incidence in these areas of Great Britain was about half that found in the two Swedish cities

Standardized morbidity rates of *cervical fractures* in Malmo were higher ($P < 0\ 05$) than those in Dundee and Oxford (Table 20) There was no significant difference in morbidity rates of *trochanteric fractures* between Malmö and the two British cities This trend was present in both sexes

Apparently there are geographical differences in the incidence of fracture of the proximal end of the femur It was further revealed that cervical fractures were responsible for this difference whereas the incidence of trochanteric fractures was about the same in the areas studied These facts have to be considered in relation to the reported predominance of trochanteric fractures in Great Britain and in the U S A which contrasted to the findings of this study (page 23)

It seems unlikely that differences in the pattern of trauma were the cause of differences in the proportion of cervical and trochanteric fractures between Swedish and the British series, as there was no evidence that type or degree of trauma had any bearing upon the main type of fracture Differences in age compo ition are eliminated in the standardized morbidity rate The difference in incidence may indicate the pre ence of biological differences between the populations of the two countries In this connection it is of interest to note that MOON and URIST (1962) found among patient with osteopenia in Los Angeles that "a seemingly disproportionate number (15 per cent) were of Scandinavian stock"

SUMMARY

The age and sex incidence of fracture of the proximal end of the femur was about equal in Malmo and Göteborg Cervical fractures

Table 19 *Standardized morbidity rates in different geographical areas*

	Period	Women	Men
Malmo	1951—1960	121.1	38.4
Malm	1955—1959	1[illegible]6.5	39.8
Goteborg	1955—1959	146.3	34.0
Dundee	1953—1957	66.[illegible]	—
Dundee	1954—1958	61.[illegible]	25.4
Oxford	1954—1958	62.0	24.1

Table 20 *Standardized morbidity rates of cervical and trochanteric fractures in Malmo Dundee and Oxford*

	Period	Women		Men	
		Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures
Malmo	1951—1960	6.9	44.[illegible]	[illegible]1.0	17.4
Dundee	1954—1958	25.8	35.4	5.7	19.7
Oxford	1954—1958	28.6	33.3	10.4	13.8

were more common among women and men in Malmö than in Dundee and Oxford Trochanteric fractures were about equally common in both countries

Differences in the proportion of cervical and trochanteric fractures in geographical regions may be an index of biological differences in the population

2 *Side involved*

PREVIOUS STUDIES

Fracture of the proximal end of the femur has been reported to occur more often on the left than on the right (RIEDINGER 1874 DUHAMEL, 1947 JENSENIUS 1956) No report of right sided predominance has been found

HIRSCH and BRODETTI (1956) found experimentally that below age 60 the resistance of the femoral neck to compression force was the same on both sides but above that age it could decrease considerably on one side and stated that this might be of clinical significance in the explanation of neck fractures without reporting on which side this was most often observed

VIRTAMA (1960) found higher ash weights in bones from the right than from the left extremities in active persons In aged persons and in persons

Table 21 *Fractures in Series A grouped according to sex side and anatomical type*

Type	Side	Total series		Women		Men	
		Women	Men	Moderate trauma	Severe trauma	Moderate trauma	Severe trauma
Cervical	Right	267	56	236	25	31	23
	Left	308	79	269	38	37	40
Trochanteric	Right	150	40	124	25	26	14
	Left	150	64	130	17	30	34

Table 22 *Traffic accident fractures in Series A grouped according to sex and side*

Side	Women	Men	Total
Right	12	23	35
Left	16	48	64
Total	28	71	99

with osteopenia only a slight difference was observed NILSSON (to be published) was able to demonstrate in men differences in bone density between the right and left leg in vivo A relationship between the strength of bone and its mineral or ash content has been demonstrated by VOSE and KUBALA (1959)

PRESENT STUDY

In Series A of this material 601 fractures occurred on the left side and 513 on the right side(**) (Table 21) The prevalence of the left side was significant(**) in men but not in women and was unrelated to the type of fracture When the fractures were divided according to degree of trauma it was found that a significant left sided predominance was present only in male fracture cases with severe trauma while in women with both types of trauma and in men with moderate trauma the difference as to side was not significant The same result was obtained when first fractures only were considered Further analysis showed that fractures due to accidents in traffic were significantly more common on the left side (**) Again this difference was almost exclusively due to fractures in men (Table 22)

The distribution of side of fracture in cases with moderate or no trauma was not related to the age of the patients In the total Series A the predominance of left sided fractures was significant(*) below the age of 60 but not above that age

COMMENTS

The predominance of left sided fractures often reported was also observed in this material

The fact that fracture due to severe trauma was significantly more common on the left side suggested an exogenous factor such as the Swedish Left Hand Rule for traffic DENCKER (1962) found however that femoral shaft fractures 58 per cent of which were caused by traffic accidents were more common on the right than on the left side

SUMMARY

Fracture of the proximal end of the femur was more common on the left than on the right side The difference was more pronounced below the age of 60 more pronounced in men than in women and more pronounced after severe than after modrate trauma These facts seem to agree with experimental finding on bone density and bone strength

3 *Incidence of Second and Third Fractures*

PREVIOUS STUDIES

STEWART (1957) in a study of the incidence of fractures of the proximal end of the femur in the Eastern Region of Scotland stated that when the appropriate bilateral cases are related to survivors from the known population the incidence is approximately twenty times that of the first fracture

PRESENT STUDY

During the period under study there were 90 second fractures and 2 third fractures The interval between first and second fractures ranged from 3 months to 25 years with a mean of 6 years

To establish whether patients who had previously sustained a fracture of proximal end of the femur had an increased fracture liability compared with the general population the following method was used Annual age and sex incidence of *first fractures* in 1951—1960 was determined (Table 23) Assuming that no appreciable change in incidence occurred and that mortality in fracture patients did not differ from that of the general population of comparable age and sex the number of persons who have suffered a hip fracture before a given age can be calculated as follows if in a five year age group $x - x+5$ years the relative annual number of first fractures is $p_{x\ 5}$ the number of patients who have had such a fracture before age x Px is equal to

$$\Sigma\, 5\, p_{y\ 5} \text{ where } y = 0\ 5\ 10 \qquad x-5$$

These figures represent the accumulated risk of suffering a fracture prior

Table 23 *Age and sex incidence of first fractures of the proximal end of the femur in 1951 1960 in Malmo*

Age groups	Cervical fractures		Trochanteric fractures	
	Women	Men	Women	Men
30—39	0 02	0 03	0 00	0 02
40—44	0 06	0 07	0 02	0 05
45—49	0 17	0 07	0 05	0 08
50—54	0 36	0 12	0 15	0 11
55—59	0 58	0 28	0 19	0 17
60—64	1 01	0 46	0 37	0 21
65—69	2 02	0 52	0 79	0 49
70—74	3 10	1 32	1 56	1 13
75—79	4 53	1 68	3 04	1 86
>80	8 15	2 91	6 30	2 38

to a certain age (Fig 10) The relative number of persons in age group $x - x+5$ years who have had a fracture is $\frac{P_x - P_{x+5}}{2}$

Assuming the probability of having a second fracture to be equal to that of a first fracture the expected annual number of such fractures in the mean population of Malmö in 1951—1960 was calculated and from this the sum of expected such fractures from 1949 to 1961 (Table 24)

The calculation depended upon the assumption that the mortality of fracture patients was equal to that of the general population, and that no changes in incidence occurred However, it has been shown that the survival rate of the fracture patients was about 15 per cent below normal in the first months following fracture Thus the calculated figures must be reduced by approximately 15 per cent The reduced figures are also given in Table 24

The expected total number of second fractures thus calculated (84) was in good agreement with the observed number (90) No difference was found between expected and observed total numbers of second fracture within each sex However when the material was divided according to the main type of first fracture (Table 24) it was found that the number of second fractures observed after cervical fracture (67 or 68) was higher ($P < 0.05$) than expected (53) The expected number of second fractures *in women after cervical first fracture was 48 and the observed number* was 56 or 57 in men the corresponding figures were 5 and 11 respectively so that this tendency was apparent in both sexes

The number of recurrent fractures after trochanteric fractures did not differ from that expected

Table 24 *Observed and expected number of second fractures in 1949—1961*

Fracture type First	Fracture type Second	Sex	Calculated annual No	Calculated No in 1949—61	Reduced No in 1949—61	Observed No in 1949—1961 Total	A	B
Cervical	Cervical	W	2 595	33	8 6	32	31	1
		M	0 243	3 2	2 7	6	6	0
Cervical	Trochanteric	W	1 78	?3 1	19 6	24	5	19
		M	0 198	2 6	2 2	5	3	2
Trochanteric	Cervical	W	1 416	18 4	15 6		5	2
		M	0 ?10	[illegible]	? 3	1	0	1
Trochanteric	Trochanteric	W	1 003	13 0	11 1	11	[illegible]	4
		M	0 1 6	2 3	2 0	3	2	1
Unknown	Cervical	W				1	1	0
Total		W			74 9	75	49	26
		M			9 2	15	11	4

A = *opposite side* B = *same side*

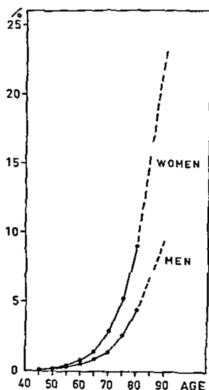


Fig 10
Cumulative risk of sustaining at least one cervical or trochanteric fracture prior to certain age calculated from the age and sex incidence in 1951—1960

COMMENTS

STEWART (1957) stated that the incidence of second fracture is about twenty times that of first fracture In the present study no difference was found in the incidence of the first and second fractures in the total series However following first fractures of cervical type there was a significantly greater risk of sustaining a second fracture which was still more pronounced when allowance was made for the observed increase in fracture incidence during the period of investigation (page 58) resulting in an overestimation of the number of expected recurrent fractures The increased risk of fracture after cervical fractures was found in both sexes

Patients with cervical fractures seemed more liable to sustain a second fracture than patients with a trochanteric fracture, possibly suggesting a difference in the etiology of the two fracture types This conclusion was strengthened by observation of a sex related difference in the incidence of cervical and trochanteric fractures (page 48) and a difference in standardized morbidity rates of cervical fractures compared with trochanteric fractures in different countries (page 50)

SUMMARY

After a cervical first fracture the risk of second fracture was increased in both sexes After a trochanteric first fracture no such tendency was found

The findings may be interpreted as indicating some difference in the etiology of the two types of fracture

4 *Comparison between First and Second Fractures Regarding Type and Side*

PREVIOUS STUDIES

STEWART (1957) stated that 'a second fracture on the same side is rare" In a material of 388 patients he found 24 patients with second fractures on the opposite side but none with a second fracture on the same side He also noted that in only two cases was the second fracture of different type and concluded that "patients who sustained fractures of the femoral neck first on one side then on the other probably exhibit the highest degree of predisposition' In an experimental study SPOTOFT (1944) obtained fractures of the same type on both sides in cadavers

PRESENT STUDY

In the present series there were 90 second fractures (Table 24), 30 of these occurred on the same side and 60 on the opposite side, indicating a higher(***) incidence of recurrent fractures on the opposite side In 38 cases where the first and second fractures were of cervical type

all but one of the second fractures occurred on the opposite side Trochanteric fracture followed a first cervical fracture in 29 patients In 21 of these patients the second fracture occurred on the same side and in 8 on the opposite side indicating that second fractures of trochanteric type were more common(*) on the same side following a cervical fracture After a first fracture of trochanteric type second fractures were equally distributed as to side

It would be reasonable to expect different type of second fracture to appear in the same proportion a first fractures provided there was no predisposition in the patient to a certain type of fracture

Thirty two women had the fracture sequence cervical—cervical and 24 women the sequence cervical—trochanteric Analysis revealed no significant difference between the observed and the expected distribution of the main types of second fractures following first fractures of cervical type

Thirty one women with a second fracture on the opposite side showed the sequence cervical—cervical and 5 patients the sequence cervical—trochanteric indicating that the proportion of second fractures of the same type as the first fracture was higher(*) than expected from the distribution of first fractures

The numbers of female patients with the sequence trochanteric—cervical and trochanteric—trochanteric were 7 and 11 respectively also indicating a high proportion of recurrent fractures of the same type as the first fracture

The number of males with second fractures was too small for statistical analysis

COMMENTS

In this material two fractures of cervical type seldom occurred in the same hip In patients with a first cervical fracture a second fracture of trochanteric type was more often seen on the previously injured side In the total series 30 of 90 second fractures occurred on the same side These findings only partly agree with STEWART s (1957) statement that 'a second fracture of the same side is rare'

The tendency found by STEWART (1957) for bilateral fractures in females to be of the same type was confirmed in this series

SUMMARY

Two cervical fractures seldom occurred in the same hip Bilateral fractures tended to be of the same type

Table 25 *Standardized morbidity rates in 1951—1955 and 1956—1960 in Malmo*

Period	Cervical fractures		Trochanteric fractures	
	Women	Men	Women	Men
1951—1955	75 8	18 5	39 0	11 3
1956—1960	79 0	23 0	48 8	21 3

5 *Are Fractures in the Aged Becoming More Frequent?*

PREVIOUS STUDIES

BUHR and COOKE (1959) found an increase in the frequency of fracture of the proximal end of the femur in the Oxford region which they ascribed to the changing age and sex distribution of the population MÅRTENSSON (1962) found an increase in the incidence of fracture of the proximal end of the femur in Goteborg which could not be entirely explained by age and sex changes in the population He did not distinguish between cervical and trochanteric fractures

PRESENT STUDY

During the period of this study the annual number of fracture cases increased continuously (approximately trebling) over the 13 years (Fig 2) whereas the total population increased by less than 20 per cent The standardized morbidity rates increased from the period 1951—1955 to the period 1956—1960 (Table 25) indicating that the increase in fracture incidence could not be entirely accounted for by changes in the age and sex composition of the population The increase was most apparent in trochanteric fractures in men

From the age and sex fracture incidence in 1951—1960 the expected number of fractures was calculated for 1950 1955 and 1960 as were the expected numbers of fractures in the five year periods 1951—1955 and 1956—1960 The expected numbers in 1949—1950 and in 1961 were extrapolated from the figures of 1950 1955 and 1960 Thus the expected numbers of fractures in 1949—1950 1951—1955, 1956—1960 and 1961 could be compared with observed numbers in the corresponding periods (Table 26 and Fig 11)

An increase was evident in the incidence of fractures in persons above the age of 30 during the period studied The figures for 1949 and 1950 were considerably lower than for the rest of the period but even when these two years were excluded the trend remained In 1961 there was no difference between the observed and the expected number of fractures

Table 26 *Observed and expected number of fractures grouped according to period sex and type*

		Women		Men		Total
		Cervical fractures	Trochanteric fracture	Cervical fractures	Trochanteric fractures	
1949—50	Observed	8	[illegible]5	13	8	1[illegible]4
	Expected	97	52	[illegible]9	24	202
			(P<0 0)	(P<0 05)	(P<0 05)	(P<0 05)
1951—55	Observed	81	141	4	48	544
	Expected	[illegible]86	158	83	68	595
					(P<0 05)	(P<0 05)
1956—60	Observed	360	2[illegible]0	104	99	783
	Expected	350	199	99	81	729
			(P<0 05)		(P<0 05)	(P<0 05)
1961	Observed	85	49	25	[illegible]0	179
	Expected	78	45	22	1	16[illegible]

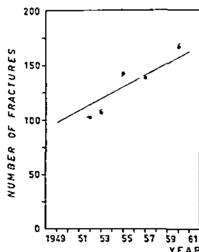


Fig 11
Observed and expected number of fractures of the proximal end of the femur in Malmo in 1949—1961 Standard deviation in 1950 1955 and 1960 is = $\sqrt{0.9\ E}$ where E = the expected number of fractures in corresponding year

Division of the material according to sex and fracture type (Table 26) showed that except for the years 1949—1950 the expected incidence of cervical fracture in both sexes was similar to that observed The observed number of trochanteric fractures in men was lower (P < 0 05) than expected in 1949—1950 and 1951—1955 and higher (P < 0 05) than expected in 1956—1960 In 1961 there was no difference In women the observed number of trochanteric fractures was lower (P < 0 05) than expected in 1949—1950 and higher (P < 0 05) than expected in 1956—1960 In 1951—1955 and in 1961 there was no difference between observed

Table 27 *Observed and expected number of first fractures grouped according to period sex and type*

		Women		Men		Total
		Cervical fractures	Trochanteric fractures	Cervical fractures	Trochanteric fractures	
1949—50	Observed	78	24	12	8	122
	Expected	92	49	28	22	191
			(P<0 05)	(P<0 05)	(P<0 05)	(P<0 05)
1951—55	Observed	270	138	74	47	529
	Expected	271	146	79	66	562
					(P<0 05)	(P<0 05)
1956—60	Observed	336	196	99	95	726
	Expected	331	183	94	78	686
					(P<0 05)	(P<0 05)
1961	Observed	80	43	25	17	165
	Expected	73	42	21	17	153

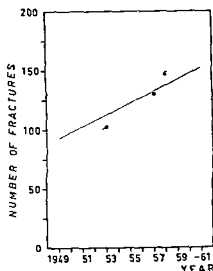


Fig 12
Observed and expected number of first fractures of the proximal end of the femur in Malmö in 1949—1961

and expected numbers of fractures The increase in fracture incidence was thus mainly caused by trochanteric fractures

As patients with a cervical fracture appeared to be more than normally susceptible to a second fracture of the proximal end of the femur (page 54) it was suspected that the observed increase in fracture incidence during the study was due to an increase in the number of second fractures Accordingly the incidence of first fracture was evaluated in the same way as were all fractures in the total material (Table 27 and Fig 12) First fractures were less numerous (P < 0 05) than expected in 1949—1950 and 1951—1955

and more numerous ($P < 0.05$) than expected in 1956—1960 In 1961 there was no deviation from the expected number

Examination of first fractures with regard to sex and main type revealed that—with the exception of the years 1949—1950 — observed values corresponded closely to expected values for cervical and trochanteric fractures in women and cervical fractures in men Trochanteric fractures in men showed an increase during this period The increased incidence of trochanteric fractures in women observed in the total series was related to a greater number of second fractures during the latter part of the period Thus 3 out of 141 female trochanteric fractures in 1951—1955 were second fractures compared to 26 out of 220 in 1956—1960 (2 of these cases were third fractures) In men 1 out of 48 trochanteric fractures was a second fracture in 1951—1955 and 4 out of 100 in 1956—1960

The real increase in the incidence of trochanteric fractures in men could not be explained by a higher frequency of severe trauma e g traffic accidents The ratio of severe moderate trauma in different periods were as follows 1949—1950 3 5 1951—1955 25 23 1956—1960 41 59 and 1961 6 14 indicating no difference in the relative frequency of severe trauma in the various period

COMMENTS

The increase in fracture incidence in this series could not be entirely explained by age and sex changes in the population at risk MARTENSSON (1962) did a similar observation in Goteborg In the present series the increase was mainly due to trochanteric fractures which are certainly less likely to escape diagnosis than cervical fractures Therefore it is improbable that the change was due to deficient registration during the earlier part of the period The increase could not be ascribed to a rise in the frequency of severe trauma such as traffic accidents

SUMMARY

An increase in fracture incidence was observed in Malmo over the period between 1949 and 1961 This increase was mainly due to trochanteric fractures The increase in female fracture cases was partly due to a higher frequency of second fractures during the latter part of the period In men the increased fracture incidence could not be ascribed to second fractures or to a rise in the frequency of severe trauma

6 *Expected Number of Fractures in the Future*

PREVIOUS STUDIES

Using incidence data STEWART (1955) calculated the number of fractures expected to occur in 1965 and 1975 in the Dundee area similarly MARTENSSON (1962) calculated the number of fractures expected in Göteborg in the periods 1960—1964 and 1965—1969 based upon the age and sex fracture incidence in the period 1940—1944 and 1955—1959 Both authors predicted a considerable increase in the total annual number of fractures during the next decade The need for hospital care of these cases will increase to the same extent if no changes take place in methods of treatment

PRESENT STUDY

City authorities in Malmö have calculated the number age and sex distribution of the city population in 1965, 1970 and 1975 By *means of age and sex fracture incidence data from the present material* the number of fracture cases in 1961—1965 1966—1970 and 1971—1975 were calculated using incidence during the five year period 1956—1960 and ten year period 1951—1960 as a base Results are given in Figure 13

It is apparent from this that the number of fractures will increase considerably Thus between 964 and 1,038 fractures may be expected in 1966—1970 and between 1 099 and 1 182 fractures in 1971—1975 in contrast to 788 cases in 1956—1960

Because the observed rate of increase is only partly explained by age changes in the population (page 58), it is probable that figures based upon the ten year period are too low and that those based on the five year period 1956—1960 should be regarded as minimum figures

Of the 1 114 fracture cases in Series A, 991 cases (89 per cent) were admitted to the Orthopaedic Clinic of MGH Twenty two patients were treated as out patients or by private physicians One hundred and twenty eight cases (11 per cent) sustained their fractures while patients in nursing homes or mental hospitals and 91 of these remained there for treatment Ten patients were treated in clinics other than the Orthopaedic Clinic of MGH It is apparent that about 90 per cent of the fracture cases required care in an acute hospital, 7 6 per cent were treated at the institutions where they lived before fracture and 1 9 per cent were not admitted to a hospital

During the period 1949—1958 the average length of stay in the Orthopaedic Clinic of MGH for patients with hip fractures was 91 days If one considers only those admitted to hospital primarily because of the fracture the average period in hospital was 94 days A majority of trochanteric fractures were treated by traction which partly explain the comparatively

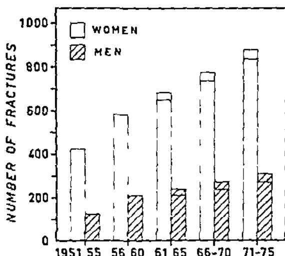


Fig 13
Observed number of fractures of the proximal end of the femur in Malmö in 1951—1955 and 1956—1960 and calculated number in 1961—1965, 1966—1970 and 1971—1975. Calculation based upon the five year period 1956—1960 (higher values) and the ten year period 1951—1960 (lower values)

long stay in hospital. In the last two or three years a more active attitude was adopted regarding earlier ambulation and weight bearing so that the average period of treatment in 1961 at the Orthopaedic Clinic of MGH was 58 days. If this is accepted as a minimum period of hospital care for a patient treated in Malmö the total number of hospital care days in the years 1970 and 1975 for patients with fractures of the proximal end of the femur will be approximately 11 600 and 13 150 respectively. This assumes that only acute care is given in hospital and that 90 per cent of such fracture cases are admitted to an acute ward. In the years 1970 and 1975 approximately 32 and 36 beds respectively will be continuously occupied by these patients compared with 26 beds in 1961.

COMMENTS

The absolute and relative increase in the number of fractures of the upper end of the femur predicted for the immediate decades will have an impact on the need for institutional medical care. However this increase in fracture cases cannot be immediately translated into a corresponding need for hospital beds as distinguished from nursing home beds and facilities of similar nature. Changes in the method of treatment, for example from traction to nailing, and in the policy concerning permission of weight bearing may influence the need for acute hospital beds. The total effect on the community, however, will probably be roughly proportional to the increase in the number of fractures. Preliminary data suggest that whereas much can be done to shorten the primary hospital stay, little can be done to shorten the entire period of institutional care needed for these often severely debilitated patients.

views in 1960 Twenty eight patients (25 women and 3 men) were excluded as mental changes made their recollection unreliable The ages of the remaining patients at the time of their first fracture of the proximal end of the femur and at interview are shown in Table 29 This group is referred to as Series A_1

Ninety nine women and one man (24 per cent and 0 9 per cent, respectively of women and men with reliable histories) had sustained a fracture of the distal end of the forearm prior to the time of interview Available records and radiographs confirmed that 85 of these 100 fractures were the Colles type Records were not available in the other 15 cases but anamnestic data left little doubt as to the diagnosis Fourteen women sustained a fracture of the distal forearm coincident with a fracture of the proximal end of the femur Sixty six women and one man sustained a distal forearm fracture prior to their first femur fracture

AFFRAM and BAUER (1962) calculated the annual incidence of distal forearm fracture in different age groups of the population of Malmö in 1953 – 1957 The material was estimated to constitute not less than 95 per cent of all diagnosed distal forearm fractures among residents of Malmö from 1953 through 1957

Assuming mortality of patients with a distal forearm fracture to be similar to that of the general population, the method described on page 53 was used to calculate the number of patients between age 30 and 79 in Series A_1 expected to have sustained a distal forearm fracture The results are given in Table 29 *A correction was applied for an estimated 5 per cent* of forearm fractures escaping diagnosis

Sixty four women and one man of Series A_1 between age 30 and 79 had a fracture of the distal end of the forearm before interview in 1960 The expected numbers were 32 3 and 1 5 respectively The difference was significant ($P < 0\ 05$) in women but not in men Sixty women in Series A_1 had such a forearm fracture before their first fracture of the proximal end of the femur compared with the expected 36 0 ($P < 0\ 05$)

Three hundred and eleven women of Series A_1 had their first femur fracture in association with moderate or no trauma (Series A_{1m} Table 29) Fifty two of these patients had sustained a previous fracture of the distal end of the forearm in comparison to an expected number of 30 1 ($P < 0\ 05$)

The observed and expected numbers of fractures of the distal end of the forearm in five year periods prior to first fracture of the proximal end of the femur in women are shown in Table 30 Between 0 and 4 years and 5 and 9 years there were more ($P < 0\ 05$) forearm fractures than expected while between 10 and 14 and 15 and 19 years prior to the femur fracture

Table 29 *Age and sex incidence of distal forearm fractures in Malmo and observed and expected number of such fractures in Series*

Age groups	Distal forearm fractures in 1953—1957 in Malmo Known second fractures excluded				Age of patients in series A_1					Observed No of patients with distal forearm fracture				
	No of		Annual incidence		at interview		at first fracture		at first fracture in series A_{1m}	before interview		before first fracture Series A_1		before first fracture Series A_{1m}
	Wom	Men	Wom	Men	Wom	Men	Wom	Men	Women	Wom	Men	Wom	Men	Women
30—34	18	11	0 41	0 28	—	—	1	1	1					
35—39	12	16	0 27	0 39	—	3	—	3	—					
40—44	31	29	0 70	0 54	2	2	6	8	5					
45—49	50	18	1 15	0 47	6	5	13	4	12					
50—54	123	11	3 3	0 34	14	7	27	9	20			1 (2)	1	1
55—59	159	13	4 92	0 30	21	7	38	12	29	5	1	7 (2)		4 (1)
60—64	141	14	5 33	0 67	40	15	56	16	46	11		6		5
65—69	139	11	6 08	0 63	57	8	75	15	67	15		12 (3)		11 (3)
70—74	87	7	4 79	0 50	77	21	85	24	73	15		1 (3)		14 (1)
75—79	67	6	5 28	0 69	80	21	71	12	58	18		19 (2)		17 (2)
Total					297	89	372	104	311	64	1	60 (12)	1	52 (7)
Expected No of distal forearm fractures										32 3	1 5	36 0	1 6	30 4

Bracketed figures denote forearm fractures sustained at the same time as the femoral neck fracture

Table 30 *Observed and expected number of distal forearm fractures in different periods before first fracture of the proximal end of the femur in women in Series A_1*

	Years before first fracture of the proximal end of femur			
	0—4	5—9	10—14	15—19
Observed	16	15	9	8
Expected	9 3	8 4	7 0	5 1
	(P<0 05)	(P<0 05)		

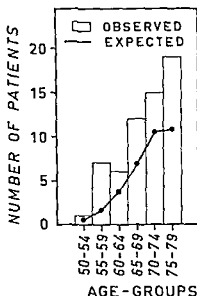


Fig 14
Observed and expected number of patients in different age groups in series A_1 with at least one distal forearm fracture prior to the first fracture of the proximal end of the femur

the expected and observed numbers of forearm fractures were about similar

The unexpectedly large number of previous forearm fractures in women of Series A_1 was unrelated to their age at the time of femur fracture (Fig 14)

In Series A_1 there was no relation between the proportion of cervical and trochanteric fractures and the occurrence of earlier forearm fracture

COMMENTS

Data now available indicate that distal forearm fractures as well as fractures of the proximal end of the femur may be regarded as symptoms of age changes in the skeleton BAUER (1960) concluded that symptoms of disturbed skeletal metabolism in women should be looked for one or two decades before the time of the hip fracture and stated that, compared with other criteria of age changes in the human skeleton the incidence of fracture is the most revealing (BAUER 1962)

In support of this idea it was shown in this series that in women with fracture of the proximal end of the femur distal forearm fracture was more common than expected and had occurred prior to the first hip fracture significantly more often than expected This indicates a relation hip between these two fractures presumably due to a change in the strength of the skeleton associated either with reduced skeletal mass (osteopenia) or possibly a change in the quality of the bone apart from osteopenia (BAUER 1962)

The data indicate that women with a distal forearm fracture have an increased risk of fracture of the proximal end of the femur in later life

SUMMARY

Women with a fracture of the distal end of the forearm are *more liable to sustain a later fracture of the proximal end of the femur* than women in the general population

II ASSOCIATED CONDITIONS

Aside from trauma several medical conditions are of importance in the etiology of fracture of the proximal end of the femur Such conditions may be (1) localized changes in the bone at the site of fracture or (2) more generalized diseases leading to increased bone fragility in the entire skeleton

COOPER (1824) gave evidence of the significant role of age changes in bone in the etiology of such fractures This has also been suggested by more recent epidemiological studies (BRUNS 1882 STEWART 1955 BUHR and COOKE 1959 BAUER 1960) URIST (1960) and STEVENS et al (1962) showed that osteopenia as evaluated by various radiodiagnostic methods was more common in patients with fracture of the proximal end of the femur than in controls VOSE et al (1961) found experimentally that osteopenic human bones broke under loads smaller than those required to break normal bones BAUER (1962) stated that bone fragility need not necessarily be related to osteopenia

To examine some of the factors directly or indirectly responsible for fractures of the proximal end of the femur it was decided to attempt evaluation of the impact of some diseases upon the liability to fracture of patients in Series A of this material The numbers of patients suffering from the diseases studies are listed in Table 31 Several patients suffered from two or more of the diseases listed For example all but one of the patients who had received cortisone therapy also suffered from severe rheumatoid arthritis Similarly a majority of patients confined to bed or

Table 31 *Associated conditions in fracture cases in Series A*

Associated conditions	Sex		Evaluable case histories		Per cent of cases	
	Wom	Men	Wom	Men	Wom	Men
Post radiotherapy	14	1	831	223	1 7	0 4
Hemiplegia						
fracture side	32	4	863	237	3 7	1 7
opposite side	7	4	863	237	0 8	1 7
Other paresis of fractured leg	8	6	863	237	0 9	2 5
Rheumatoid arthritis	64	4	863	237	7 4	1 7
Cortisone therapy	8	—	831	223	1 0	—
Hyperthyroidism	7	—	831	223	0 8	—
Diabetes mellitus	48	5	863	237	5 6	2 1
Post gastric surgery	11	18	831	223	1 3	8 1
Non ambulant	53	9	830	236	6 4	3 8
Parkinsonism	19	3	863	237	2 2	1 3

Table 32 *Mean ages of patients in Series A according to presence or absence of predisposing factors*

		With predisposing factor			Without predisposing factor		
		No	Mean	Error of mean	No	Mean	Error of mean
Radiotherapy	Women	14	66 6	2 64	861	73 1	0 37
Hemiplegia (fracture side)	Women	32	71 2	1 41	843	73 0	0 38
Other paresis (fracture side)	Women	8	54 1	5 34	867	73 1	0 36
	Men	6	47 8	4 22	233	69 6	0 89
Rheumatoid arthritis	Women	64	66 4	1 27	811	73 5	0 38
Cortisone therapy	Women	8	57 9	2 87	867	73 1	0 37
Hyperthyroidism	Women	9	67 7	3 87	866	73 0	0 37
Diabetes mellitus	Women	48	72 5	1 08	827	73 0	0 38
Post gastric surgery	Women	11	65 3	3 62	864	73 0	0 37
	Men	18	68 6	2 14	221	69 0	0 96
Non ambulant	Women	53	74 5	1 51	825	72 6	0 41
	Men	9	72 7	2 87	230	68 8	0 94
Parkinsonism	Women	19	75 1	1 75	856	72 9	0 37
Castration prior to 50 without radiotherapy	Women	11	65 9	2 99	850	73 2	0 36

chair had some disease as cause of their invalidism The average ages at fracture in different disease groups are given in Table 32

Aside from the conditions listed in Table 31 other coincident diseases

were often recorded Cardio va cular di ea e (uncomplicated hypertension and arterio clerosis excluded) e g was recorded in 8 2 per cent of the ca es and 1 7 per cent had a history of previous myocardial infarction 5 3 per cent of the fracture patients were blind or had considerably reduced eye sight and 3 6 per cent were admitted to mental ho pital at the time of fracture

1 *Local Conditions*

a *Post radiotherapy*

PREVIOUS STUDIES

Radiotherapy directed toward malignancies in the pelvi usually cancer of the uterus or ovarie or meta tatic le ions in the inguinal lymph gland ometimes cau e pontaneous fracture of the neck of the femur BAENSCH (1927) was the fir t to de cribe such fracture and since then many reports have appeared (for reference see BONFIGLIO 1953 KOK 1953 BICKEL et al 1961)

PRESENT STUDY

In Series A radiotherapy had been directed towards the pelvis prior to fracture in 14 women and one man (Table 33) Patients who had radiotherapy as treatment of o teoarthritis of the hip were not included as the do e given in the e ca es was small compared with that given in ca es of malignancy Cancer of the uterine cervix (7 case) and cancer of the ovaries (3 ca es) were the most common conditions receiving radiotherapy The male patient in the group had been treated for cancer of the bladder There was no radiographic evidence of metastatic lesions at the site of fracture in these patients

Eight patients (7 women and 1 man) sustained fracture without a history of injury In these ca es the fracture appeared within 17 months following radiotherapy All but one were subcapital impacted fractures Radio therapy must be strongly suspected as the rea on for fracture in these patients The average age of the e 7 women (63 7 $\pm$ 2 97 years) was lower(**) than in the rest of the eries of female cervical fracture ca e

In 7 patients moderate injury was recorded Three of these had trochan teric fractures None of the cervical fractures in these patients were im pacted Only 2 of the e 7 patients were younger than the average female fracture patient

The average age of the total eries of radiation treated women was lower(*) than in the rest of the serie

Table 33 Fractures preceded by radiotherapy for various conditions

Code No	Sex	Age	Fracture type	Trauma	Interval between treatment and onset of symptoms	Largest roentgen dose	Diagnosis
578	W	62	SCi	Moderate	10 months	Fractured hip	Carcinoma of uterine cervix
877	W	62	SCi	None	1 month	Fractured hip	Carcinoma of uterine cervix
997	W	57	SCi	None	4 months	Equal both hips	Carcinoma of uterine cervix
812	W	72	SCi	None	6 months	Equal both hips	Carcinoma of uterine cervix
586	W	79	TC	Moderate	13 years	Equal both hips	Carcinoma of uterine cervix
733	W	74	T	Moderate	2 weeks	Fractured hip	Carcinoma of uterine cervix
1037	W	44	T	Moderate	4 years	Equal both hips	Carcinoma of uterine cervix and corpus
723	W	72	SC	Moderate	3 months	Equal both hips	Carcinoma of uterine corpus
1047	W	71	SC	Moderate	4 months	Radium only	Carcinoma of uterine corpus
914	W	63	SCi	None	13 months	Equal both hips	Ovarian carcinoma
996	W	56	SCi	None	11 months	Fractured hip	Ovarian carcinoma
834	W	67	T	Severe	4 years	Fractured hip	Ovarian carcinoma
350	W	79	T	Moderate	1 month	Opposite hip	Melanosarcoma of vulva
696	W	74	TC	None	2 months	Fractured hip	Reticulum cell sarcoma
158	M	67	SCi	None	Not known	Fractured hip	Carcinoma of urinary bladder

SC subcapital TC transcervical T trochanteric i impacted

b *Neurologic conditions*

PREVIOUS STUDIES

In a series of fracture patients with *hemiplegia* PESZCZYNSKI (1957) found that all the fractures were on the hemiplegic side SOTO HALL (1960) was of the opinion that fracture of the hip is an extremely common complication of hemiplegia and stated that 8 to 10 per cent of hemiplegics sustain fractures of the hip which usually occur on the hemiplegic side

PESZCZYNSKI believed that an impaired kinesthetic sense in patients with brain damage was responsible for an increased tendency to fall and that any changes in the bones on the hemiplegic side which might have influenced a prevalence of the fracture on the hemiplegic side must be excluded as a primary etiologic factor However it has been observed that disuse of a limb due to neurological disorders injuries or immobilization results in loss of bone substance in the affected limb (ARMSTRONG et al 1945 ABRAMSON, 1948 SISSONS 1952 WHEDON 1952 GILLESPIE 1954) GILLESPIE (1954) found in experimental animals that the bending moment at breaking point was significantly lower in bones of the affected than of the unaffected leg

PRESENT STUDY

Hemiplegia was recorded in 47 patients of Series A (4 2 per cent) Seven of these patients had a transient paresis and only slight symptoms were found at the time of admission for their fracture In 36 patients the fracture was on the hemiplegic side in the remaining 11 patients it was on the normal side In the 39 women the prevalence of fractures on the hemiplegic side was significant(***) while in the 8 men the fractures were equally distributed

The average age of the hemiplegic patients did not differ from the average age of the rest of Series A patients This was expected as hemiplegia is mainly a disease of old age

Other neurologic conditions of the lower extremities were *poliomyelitis* (2 women and 5 men) *multiple sclerosis* (3 women and 2 men) and *spasticity* of varied etiology (3 women) All but one of the patients with poliomyelitis sustained their fractures on the paretic side Nine fractures in this mixed group were cervical and 7 trochanteric type The average age at fracture was lower(***) in both sexes than in the rest of the series Severe trauma was recorded in 4 women and 2 men with fracture of the affected leg In 3 of the women it was related to a transient hemiplegia

2 *General Conditions*

a *Rheumatoid arthritis*

PREVIOUS STUDIES

Rheumatoid arthritis is known to have a marked influence upon the metabolism of the skeleton (McCONKEY et al 1962) Juxta articular osteopenia can be observed radiographically in very early stages of the disease (STEINBROCKER et al 1949) MANPEL et al (1961) reported that 0 6 per cent of their patients with fracture of the proximal end of the femur suffered from rheumatoid arthritis

PRESENT STUDY

Rheumatoid arthritis was recorded in 64 women and 4 men After cardio vascular disease it was the most common disease recorded in women It was more common in younger age groups than in older ones Below 60 years of age 15 per cent of female patients had rheumatoid arthritis, between 60 and 69 years the incidence was 11 per cent between 70 and 79 years 7 0 per cent and above 80 years 1 6 per cent The average age of female patients with rheumatoid arthritis was lower(***) than in the rest of the series In these patients the distribution of moderate and severe trauma did not differ significantly from that in Series A (7 8 per cent evere trauma and 12 per cent respectively) nor did the distribution of cervical and trochanteric fractures (43 cervical and 21 trochanteric fractures) Ten patients with rheumatoid arthritis were confined to a chair (9 patients) or bed (1 patient) before fracture

b *Endocrinopathy*

PREVIOUS STUDIES

Several endocrine disorders may disturb bone metabolism Hyper adrenocorticism in Cushing s disease and prolonged corti one medication cause marked osteopenia and bone fragility (REIFENSTEIN JR 1947 ARNOLDSON 1958 LINDAHL, 1961 and others) Hyperthyroidism (WILLIAMS and MORGAN 1940 FOLLIS 1953) and diabetes mellitus (ALBRIGHT and REIFENSTEIN 1948 HERNBERG 1952) have a similar but less pronounced effect

PRESENT STUDY

In Series A no patient had Cushing s disease or hyperparathyroidism *Cortisone medication* had been received by 7 women with rheumatoid arthritis and one woman with asthma Their mean age was lower(***) than average and all the fractures were associated with *moderate* trauma Cervical and trochanteric fractures were equally common

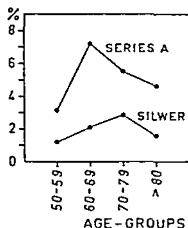


Fig 15
Distribution of diabetes mellitus in women in series A and according to SILWER (1958)

Hyperthyroidism had been diagnosed in 9 women prior to fracture All the fractures were caused by moderate trauma and all but one were of cervical type Their average age did not differ from that of the rest of the series

Diabetes mellitus had been recorded in 47 women and 5 men in Serie A One woman suffered two fractures during the ten year period studied In 3 women the digno is was made during the course of fracture treatment Twenty one patients with diabetes recognized prior to the fracture had received insulin therapy while the remaining 31 had had only diet control The average age at fracture of diabetic patients did not differ from that of non diabetics nor did the distribution of moderate and severe trauma

With the exception of diabetes the prevalence of coexisting diseases in the present material cannot be compared with that in the general population While no data are available on the prevalence of diabetes in the city of Malmo SILWER (1958) published data on the incidence of diabetes mellitus in town and rural districts of the County of Kristianstad which is situated in the same area of Sweden as Malmö Silwer found a higher frequency of diabetes in towns than in rural districts It seemed reasonable to assume that incidence data from the towns of the County of Kristianstad could be compared with Series A of this material SIEVERS et al (1961) compared the incidence in Malmö of diabetes in patients suffering from coronary heart disease with the incidence of diabetes given by Silwer

In making such a comparison only patients whose diabetes had been recognized before their admission for hip fracture were included The distribution of female diabetics in this series and in Silwer's series is shown in Fig 15 If Silwer s data are projected upon the number of fracture cases

Table 34 *Observed number of diabetics in Series A compared with expected number calculated from the incidence according to Silwer (1958)*

Age group	Women			Men		
	No of fractures	Expected No	Observed No	No of fractures	Expected No	Observed No
50—59	82	0.9	3	27	0.2	1
60—69	189	4.0	13	47	0.6	1
70—79	318	9.0	18	82	1.5	3
>80	219	3.3	10	46	0.6	—
Total	808	17.2	44	202	2.9	5

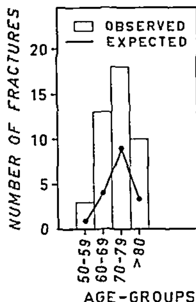


Fig 16
Observed number of fractures in female diabetics in Series A and the expected number from data given by SILWER (1958)

of corresponding age and sex and who had reliable case histories the expected number of diabetics in each sex can be calculated (Table 34 and Fig 16) The expected number of diabetic female fracture cases was 17.2 as compared to 44 observed cases ($P < 0.05$) The ratio of observed to expected numbers was about the same in each ten year age group (Fig 16)

In men no difference was found between expected and observed numbers of diabetics

The degree of trauma was not considered in the above calculations When fractures associated with moderate trauma only were included 15.1 women diabetics would have been expected compared with the 39 cases observed in the material ($P < 0.05$) The corresponding figures in men were 1.6 expected and 3 observed revealing no significant difference

Comments When data on the incidence of diabetes mellitus in urban residents of the County of Kristianstad were applied to this material diabetes seemed to be significantly more common in women with fractures than in the general population

HERNBERG (1952) in post mortem studies found a greater degree of osteopenia in diabetic subjects below the age of 65 than in non diabetic controls while above that age there was no difference in degree of osteopenia between the two groups *In this series there was no certain difference* between the relative number of diabetics in the younger and older age groups

c *Post gastric surgery*

PREVIOUS STUDIES

Operations upon the gastro intestinal tract may result in defective absorption of substances essential for normal bone metabolism For this reason CASUCCIO (1962) included previous gastrectomy among the causes of osteopenia MCLEAN BAIRD and OLFESKY (1957) reported 4 cases of osteomalacia after such operations DYMLING et al (1962) and HALL and NEALE (1963) *reported several cases of* osteopenia in patients following gastric operations URIST (1960) found that the incidence of duodenal ulcers was 18 per cent in osteopenic men while in a control group it was only 9 per cent

PRESENT STUDY

Gastric operations had been performed in 29 patients (11 women and 18 men) Subtotal gastrectomy had been done in 9 women (in 3 cases for carcinoma of the stomac) and 14 men and gastro enterostomy in 1 woman and 2 men In 3 patients records of the operation could not be obtained The distribution of moderate and severe trauma according to sex did not differ from that of the total series nor did the average age in men However the average age at time of fracture of women with gastric operations was lower(*) than in the rest of the series Earlier gastric *surgery was the most common concomitant condition recorded in male* patients (8 1 per cent)

d *Immobilization*

PREVIOUS STUDIES

Immobilization *results in a loss of skeletal* mass (ARMSTRONG et al 1945 ABRAMSON 1948 SISSONS 1952 WHEDON 1952 GILLESPIE 1954) probably leading to an increased liability to fracture

MANFEL et al (1961) found that 21 per cent of 486 patients were not ambu

latory prior to fracture RENO and BURLINGTON (1958) classified 35 per cent of their 146 patients as invalids or semi invalids but did not give definitions *In this study patients known to have been bedridden or mainly confined to a chair for months prior to the fracture were classified as non ambulant*

PRESENT STUDY

Of all patients whose degree of mobility was known in this series 53 women and 9 men were classified as non ambulant before the hip fracture (6 4 and 3 8 per cent, respectively) Sixteen patients had been bedridden for a long period 34 patients had sequelae of cerebral vascular lesion (18 patients), rheumatoid arthritis (8 patients), parkinsonism (5 patients) or spastic paraplegia (3 patients) and in 3 patients some other invalidity was present (osteoarthritis amputation deformity due to old fracture) The remaining patients were non ambulant because of the general debility of old age advanced tuberculosis or carcinoma The average age in this group was the same as that of the rest of the series All fractures but 4 were associated with moderate trauma

e *Parkinsonism*

PREVIOUS STUDIES

Patients with parkinsonism probably have a greater risk of fracture than healthy people of the same age due to reduced mobility and increased tendency to fall MANFEL et al (1961) and RENO and BURLINGTON (1958) found the incidence of parkinsonism in their series to be 1 0 and 1 4 per cent respectively

PRESENT STUDY

Parkinsonism was found in 19 women (2 2 per cent) and 3 men (1 3 per cent) in this series The average age of these patients was *the same as that of the rest of the material With the exception of one man* moderate trauma was recorded in all of these patients

COMMENTS

Because of a lack of data on the prevalence of diseases in the population studied it was not possible to state whether diseases known or suspected to affect the skeleton were more prevalent in this series than in the general population Diabetes mellitus was the only disease in which age and sex incidence was known (SILWER 1958)

The only way in which to study the impact of disease upon fracture etiology was to compare the average age at fracture the type of trauma

and in cases of unilateral paresis side involvement in those patients having disease with corresponding factor in patients without disease

The results of this study indicate that previous radiotherapy of the pelvis hemiplegia or other paresis of a leg rheumatoid arthritis diabetes mellitus and prolonged cortisone medication predispose to fracture No conclusion can be drawn from this material regarding any increased liability to fracture of the proximal end of the femur in non ambulant patients or in patients with parkinsonism From other reasons it seems however reasonable to assume such an increased liability It can not be established whether the lower average age at fracture in female patients with previous gastric operations compared with non operated patients was due to an increased frequency of gastric operations in women during later decades or to a greater susceptibility of the female skeleton to short circuiting operations of the gastro intestinal tract

In Series A one or more of the diseases listed was known to be present in 211 women and 48 men (24 and 20 per cent respectively) In the cases where the degree of trauma was known 300 fractures in women (35 per cent) and 145 fractures in men (62 per cent) occurred in association with severe trauma or in association with one or more of the diseases studied

The age and sex incidence of fractures of the proximal end of the femur associated with moderate or no trauma may be regarded as an index of *fracture liability* *As some* conditions are known or suspected to cause skeletal changes an index of idiopathic age changes of the skeleton may be found by excluding all cases of fracture with such concomitant disease (Fig 17) It was apparent that the increase of fracture liability appeared at an earlier age in women than in men Idiopathic fractures were more common in woman than in men but with advancing age this difference tended to diminish

SUMMARY

Several medical conditions were found to be of importance in the etiology of fracture of the proximal end of the femur

3 *Parity*

PREVIOUS STUDIES

During pregnancy calcium requirements are increased and although renal conservation of calcium occurs during the period of maximum fetal requirement (Goss 1962) and during lactation a net loss still occurs (ALBRIGHT and REIFENSTEIN 1948)

Several authors have observed marked skeletal changes during pregnancy ALBRIGHT and REIFENSTEIN (1948) and NORDIN and ROPER (1955) de

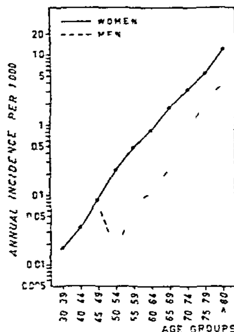


Fig 17
Age and sex incidence of fractures of the proximal end of the femur in patients without known predisposing factors and fractures after moderate or no known trauma

scribed severe osteopenia developing in healthy women during pregnancy JACKSON (1958) found that premenopausal osteopenia in 11 women had occurred in connection with pregnancy and lactation and FINLEY (1956) stated that "in elderly women the incidence of osteoporosis is in those who are multiparous is almost double that of those who are nulliparous" KESSON et al (1946) reported that the incidence of osteopenia was significantly higher in multiparous than in nulliparous women but DONALDSON and NASSIN (1954) could not confirm this finding

BAYLISS et al (1955) followed plasma 17 hydroxycorticosteroid levels in 38 women before and after delivery and found an increasing concentration up to delivery and a rapid fall in concentration after that time In some cases the values were higher than those found in CUSHING's disease ELLINGER et al (1952) observed bone resorption in rats during lactation which was most marked in cancellous bone

No reports have been found regarding a relationship between parity and liability to fractures

PRESENT STUDY

If parity had an influence upon liability to fracture of the proximal end of the femur the proportion of married women would be greater among fracture patients than in the total population The average *number of children of women with fracture would also be greater than* in the general population

Table 35 *Series A + B and population of Malmö in* [illegible] *196*[illegible] [illegible] *to age and civil st*[illegible]

Age groups	Known civil status	Unmarried No	Unmarried Per cent	Per cent unmarried in Malmö in [illegible]	1960
50—59	114	30	[illegible]	[illegible]	1[illegible]
60—69	263	[illegible]1	[illegible]	[illegible]	2[illegible]
70—79	429	11[illegible]	[illegible]	[illegible]	3[illegible]
>80	344	[illegible]	[illegible]	4[illegible]	[illegible]
Total	1 150	2[illegible]	[illegible]	[illegible]3	[illegible]0

In Series A and B civil status was known in 1 1[illegible] of 1 205 women patients (98 per cent) Per cent unmarried in each age group and per cent unmarried women in corresponding age groups in the population of Malmo are indicated in Table 35 It is evident that the civil status of the female probands did not differ appreciably from that of the female population of Malmo

Parity was known in 709 of the 1 205 women (59 per cent) The information was collected at the time of admission to hospital or at the time of interview in 1960 Lack of completeness of data in Series A was related to deaths occurring before the interview and in Series B to unreliability of the case records so that data are less complete in the older than in the younger age groups No other systematic bias was found

Average parity in the total series was 1 9 and in the married 2 5 The average parity was somewhat higher in women with trochanteric fracture than in women with cervical fracture 2 1 and 1 8 respectively (Table 36)

The average age of the patients with known parity in this series was 69 4 years A majority of these patients were born around 1885—1890 When the average parity in the female population of Sweden born in 1885 1890 and 1895 (Table 37) was compared with that of patients in this material (Table 36) it was apparent that parity was about the same in fracture patients as in the total population

Five hundred and ninety nine women in whom parity was known suffered fracture in association with moderate or no trauma The average number of children in this group was 1 9 similar to that of the total series

No data on lactation are available

COMMENTS

The relative numbers of married and unmarried women in this series did not differ from those of the total population of Malmö

The average parity of female fracture patients was slightly lower than

Table 36 *Female patients in Series A and B grouped according to civil status average parity and type of fracture*

Civil status	No of patients	Patients with known parity			Cervical fractures		Trochanteric fractures	
		No	Per cent	Average parity	No	Average parity	No	Average parity
Married	888	525	59	2 5	351	2 4	174	2 7
Unmarried	296	179	61	0 2	130	0 2	49	0 1
Not known	21	5	24	1 0	2	1 0	3	1 0
Total	1 205	709	59	1 9	183	1 8	226	2 1

Table 37 *Average parity of Swedish women born in 1885 1890 and 1895*

Women born in	Average parity	Average parity per married woman
1885	2 8	3 3
1890	2 4	2 8
1895	2 1	2 4

that of women in the total population of Sweden This was probably explained by a lower fertility rate in towns

Parity in women with trochanteric fractures was slightly higher than in women with cervical fractures This difference was probably related to the higher average age of patients with trochanteric fractures as fertility decreased considerably during the last decade of the 19th century (Table 37) The literature contains many reports on childbirth and lactation as etiologic factors in osteopenia, but this study did not reveal a correlation with fracture

SUMMARY

Parity did not influence liability to fracture of the proximal end of the femur in the patients of this series

4 *Age at Menopause*

PREVIOUS STUDIES

In 1940 ALBRIGHT et al suggested that osteoporosis was one manifestation of decreased hormone production after the menopause and observed (ALBRIGHT et al 1941) that in women with an artificial menopause the average age of onset of such skeletal changes was lower than following a physiologic menopause REIFENSTEIN (1957) concluded that

a deficiency of anabolic hormones in aged persons was a factor leading to osteoporosis

Many authors have included castration among the causes of osteopenia (ALBRIGHT et al 1941 WILSON 1953 IBARRA 1956 BARTTER 1957 SCHECHTER and MERVINE 1958 URIST 1958) URIST (1960) found a higher incidence of oophorectomy in osteopenic than in non osteopenic women

On the other hand DONALDSON and NASSIM (1954) concluded from a study of 94 patients with surgical castration (between age 26 and 73) that neither the time of onset nor the degree of osteopenia could be related to the age at menopause whether natural or artificial

As there is apparently no agreement regarding the influence of the menopause upon skeletal metabolism an attempt was made to relate age at menopause to age at fracture in this series

PRESENT STUDIES

At the time of interview in 1960 the patients in Series A were asked about their age at menopause As these data were initially regarded as somewhat unreliable the patients were classified in five year age groups However as the interviews progressed it became evident that most patients had a rather distinct memory of their age at the menopause and could nearly always give a definite answer

In Series B the age at menopause was known in 142 women Ninety six of these patients had cervical and 46 trochanteric fractures The average age at menopause was 48 4 $\pm$ 0 44 years There was no difference between the average age at menopause of the cervical and trochanteric fracture groups

Four hundred and eight women who had sustained femoral neck fractures in association with moderate or no trauma were classified in four groups with regard to age at the physiologic or surgically induced menopause (Table 38) It was apparent that no correlation was present between age at the menopause and age at fracture

Eleven women had undergone surgical castration before age 50 but without radiotherapy directed towards the pelvis In these patients the average age at fracture was 65 9 $\pm$ 2 99 years which was lower than for the rest of material(*) Four out of 11 castrated women suffered severe trauma

COMMENTS

The existence of a relationship between age changes in the human skeleton resulting in decreased bone strength and the sex hormones is still open to discussion

probands were above age 67 so it is reasonable to assume that it was not lower than that of the fracture series. The average age of the coxarthrosis series agreed rather well with that of the fracture patients.

SUMMARY

Low body weight relative to body height was more common in female patients with fracture of the proximal end of the femur than in two control series.

I SEASONAL VARIATION OF BIRTH DATES

PREVIOUS STUDIES

There are reasons to suspect that changes in the skeleton are dominant factors in the etiology of fractures of the proximal end of the femur. At the moment however it is difficult or impossible to identify symptoms of such skeletal changes apart from fracture (BAUER 1962).

It is well known that in some diseases there is a seasonal variation in the birth dates of the patients. A classical orthopaedic disease with such a seasonal variation is congenital dislocation of the hip (see ANDRÉN and PALMÉN 1963). It is also well known that some kinds of intoxication (phosphorus) and some diseases (measels) suffered in early childhood result in sclerotic areas in the skeleton. Such areas of condensed bone remain unchanged or almost unchanged throughout life.

PRESENT STUDY

As influences acting in early childhood or prenatal life may thus result in persisting alterations in the skeleton it was considered worthwhile checking whether any seasonal variation of birth dates could be demonstrated in patients with fractures of the proximal end of the femur associated with moderate or no trauma (1 058 women and 213 men). The seasonal variation of live births in Sweden from 1881 through 1890 was used as a control. The expected number of individuals in each month and difference between observed and expected number were calculated and the results are given in Table 40 and Figure 18.

It was apparent that this material showed a clear seasonal variation of date of birth with the crest of the wave in fall and the trough in early spring. During the first 6 months of the year the observed number in the total series and in women was lower ($P < 0.05$) than expected and during the last 6 months the observed number was higher ($P < 0.05$) than expected. In male patients no such trend was present. Similar result was obtained when the seasonal variation of live births in the district of Malmö (County of Malmöhus) from 1881 through 1890 was used as a control.

Table 10 Observed and expected seasonal variation of birth dates of patients with fractures associated with moderate or no trauma in series A and B

		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Women + men	Observed	115	88	96	97	100	89	124	106	1 3	125	98	118	1 271
	Expected	113.0	101.6	115.[illegible]	107.1	106.8	99.3	100.0	100.4	111.7	106.3	100.4	109.[illegible]	1 271.0
	Difference	+ [illegible]0	−13.6	−19.2	−10.1	−6.8	−10.3	+24.0	[illegible]6	+11.3	+18.7	[illegible]0.4	8.[illegible]	
Women	Observed	95	74	77	81	81	75	10[illegible]	84	106	109	78	[illegible]2	1 0[illegible]8
	Expected	93.5	85.0	95.9	89.1	89.0	82.1	83.[illegible]	83.1	93	89.0	84.0	[illegible]1.0	1 058.2
	Difference	+1.5	−11.0	−18.9	[illegible]8.1	−8.0	7.1	[illegible]7	[illegible]0.9	[illegible]12.8	[illegible]0.0	[illegible]0	[illegible]1.0	

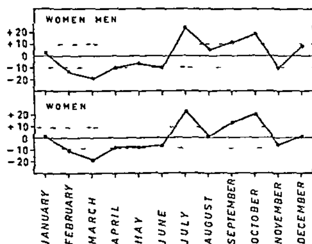


Fig 18
Differences between observed and expected seasonal variation of dates of birth of patients in series A and B with fractures after moderate or no trauma Random deviation ± $\sqrt{n \cdot \frac{1}{12} \cdot \frac{11}{12}}$

COMMENTS

The seasonal variation of date of birth observed in this material may indicate that factors other than hereditary factor e g climatic alimentary or hormonal influencing the child during prenatal life or early childhood are of importance in the etiology of the skeletal fragility of old age one symptom of which can be a fracture of the proximal end of the femur associated with little or no trauma The findings require confirmation by studies of still larger materials Patients with distal forearm fractures should also be included in such studies

SUMMARY

A seasonal variation of the date of birth was observed among patients with fractures of the proximal end of the femur associated with little or no trauma

J BLOOD GROUPS

PREVIOUS STUDIES

During recent years increasing interest has been focused upon an association between disease and blood groups To obtain data for blood group studies BUCKWALTER et al (1957) studied patients with fractures of the proximal end of the femur and found that the pattern of blood types differed from that of a series of blood donors from the same area A significantly increased incidence of blood type A was found in the fracture series THORSOE (1960) made a similar investigation in Copenhagen using a large series of blood grouped residents as controls, and found no difference in blood group distribution between the total fracture series and

Table 41 *Blood group distribution of 562 patients in Series A and B and control series*

	Cervical fractures		Trochanteric fracture		Total fracture		Control	
Blood group	No	Per cent	No	Per cent	No	Per cent	No	Per cent
0	144	39.8	69	34.5	213	37.9	2 401	42.3
A	162	44.8	98	49.0	260	46.3	2 430	42.8
B	39	10.8	27	13.5	66	11.7	590	10.4
AB	17	4.7	6	3.0	23	4.1	247	4.5
Total	362	100.1	200	100.0	562	100.0	5 668	100.0

the controls However in cervical varus fracture cases there was a significant excess of blood group A

BUCKWALTER et al suspected a relationship between blood group substances and bone metabolism

PRESENT STUDY

In Series A and B of the present study the blood group distribution in 562 patients with fractures of the proximal end of the femur associated with moderate or no trauma (43 per cent of all patients with that degree of trauma) was compared with the blood group distribution of 5 668 volonteer blood donors in the district of Malmö (County of Malmohus) (WILLERT and WINBLAD 1952) The results are given in Table 41 There was no significant excess of blood group A in the total fracture series nor in each of the two fracture types

COMMENTS

In contrast to reports by BUCKWALTER et al (1957) and THORSOE (1960) no significant excess of blood group A was present in this material

AIRD et al (1954) described a method for statistical calculation of significance in combined data from different regions By studying the data given by BUCKWALTER et al and THORSOE as well as those from Malmö (Table 42) according to that method a significant(**) excess of blood group A was found to be present in fracture patients compared with controls

ROBERTS (1957) discussed the implication of associations observed between blood groups and disease particularly duodenal ulcer and suggested that blood group substances might be involved in some way noting that many diseases with such associations are diseases of or closely associated with the upper part of the gastro intestinal tract a region in which in secretors group specific substances are present in large amounts Roberts did not rule out some hitherto unknown functions of the blood group genes which might be responsible

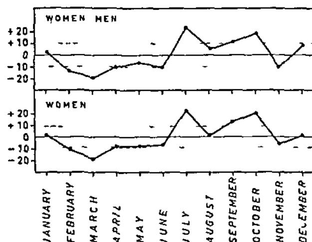


Fig 18
Differences between observed and expected seasonal variation of dates of birth of patients in series A and B with fractures after moderate or no trauma Random deviation — $\sqrt{\frac{1}{n}\cdot\frac{1}{12}\cdot\frac{11}{12}}$

COMMENTS

The seasonal variation of date of birth observed in this material may indicate that factors, other than hereditary factors, e g climatic alimentary or hormonal influencing the child during prenatal life or early childhood are of importance in the etiology of the skeletal fragility of old age one symptom of which can be a fracture of the proximal end of the femur associated with little or no trauma The findings require confirmation by studies of still larger materials Patients with distal forearm fractures should also be included in such studies

SUMMARY

A seasonal variation of the date of birth was observed among patients with fractures of the proximal end of the femur associated with little or no trauma

J BLOOD GROUPS

PREVIOUS STUDIES

During recent years increasing interest has been focussed upon an association between disease and blood groups To obtain data for blood group studies BUCKWALTER et al (1957) studied patients with fractures of the proximal end of the femur and found that the pattern of blood types differed from that of a series of blood donors from the same area A significantly increased incidence of blood type A was found in the fracture series THORSOE (1960) made a similar investigation in Copenhagen using a large series of blood grouped residents as controls and found no difference in blood group distribution between the total fracture series and

IV GENERAL DISCUSSION

A ETIOLOGY OF FRACTURE OF THE PROXIMAL END OF THE FEMUR

The modern concept of fractures of the upper part of the thighbone was formulated by COOPER (1824): the fracture occurs in aged females following trivial *trauma*, sometimes as a result of *disease*, but usually because of *bone fragility*.

1 *Trauma*

There is ample evidence that compression fractures of the vertebrae in the aged often occur without a history of trauma (GERSHON-COHEN et al 1953). COOPER (1824) observed cases of spontaneous fracture of the proximal end of the femur, and it has been claimed that these are common. The literature contains few reports to support this view. In this investigation spontaneous fracture was rare. Only 18 cases were found. Of these 3 had a cancer metastasis or other radiographically apparent lesion and 8 had received radiotherapy followed by a typically insidious development of a fracture. There seems to be little doubt therefore that trauma is an etiologic factor in fracture of the upper end of the femur.

In the younger age group in this study and especially in males severe trauma was not uncommon. In women of all age groups and in men of older age groups severe trauma was relatively rare. This age and sex pattern of trauma with fracture of the proximal end of the femur is opposite to that seen with fractures associated with severe trauma such as fracture of the shaft of the femur. Also multiple injuries were rare in this material. Because of this it seems reasonable to exclude severe trauma as a dominant factor in the etiology of fracture of the upper end of the femur.

Aged people are reported to have an increasing tendency to fall due to conditions such as giddiness, failing eyesight, impaired muscle coordination etc (SHELDON 1948, DROLLER 1955, BOUCHER, 1959). However it does not seem plausible that elderly people should generally sustain accidents of the type that result in fracture of the proximal end of the femur more often than active persons in younger age groups. It is also unlikely that elderly women would suffer minor accidents more than three times as often as elderly men. Similarly a sudden increase in the incidence of distal forearm fractures around the age of 50 in women but not in

and COOKE, 1959, ALFFRAM and BAUER 1962) can hardly be explained by a sudden increase of the number of accidents in women but not in men

When compared to changes occurring within bone external factors are probably of subordinate importance in the liability of elderly persons, particularly women, to sustain fractures of the proximal end of the femur

2 *Disease*

In this material fracture associated with severe trauma was encountered twice as often in healthy patients as in those with one or more of the associated conditions studied Local conditions such as cancer metastases or bone changes due to radiotherapy are obvious causes of fracture of the proximal end of the femur but even generalized conditions associated with diabetes mellitus and cortisone medication were found to be of probable etiologic significance In the entire material 24 per cent of female and 20 *per cent of male fractures occurred in patients who had one or more of* the following conditions previous radiotherapy to the pelvis paresis of the fractured leg, rheumatoid arthritis cortisone therapy hyperthyroidism, diabetes mellitus previous gastric surgery parkinsonism or immobilisation of long duration While it was not possible to determine the relative etiological significance of all of these conditions the fact that as a group they were associated with a significantly higher incidence of fracture associated with moderate rather than severe trauma indicated that they were of etiological significance

3 *Bone fragility*

Increased liability to fracture of the proximal end of the femur may be due to local lesions or to general changes in the skeleton Local changes caused by cancer metastases radiation injury and similar lesions were rare in this material A few authors have produced evidence of changes in the internal structure of the proximal end of the femur in the aged on radiograms (APFFLBACH and AIRES 1936 RUTISHAUSER and DUFOUR 1950 URIST 1960) and in anatomical and histological studies (LARKAS et al, 1948 RUTISHAUSER and DUFOUR 1950) However for several reasons it is probable that in the aged a general loss of bone tissue is of more importance in the etiology of such fractures In this study women with fracture of the proximal end of the femur were found to sustain more than twice as many fractures of the distal end of the forearm as women in the general population In a previous study (ALFFRAM and BAUER 1962) *it was found that the ratio of forearm fractures occurring in cancellous bone* to those occurring in cortical bone increased with age especially in women while the degree of violence associated with such fractures decreased with

age Other fractures occurring in cancellous bone are also disproportionately frequent in the aged for example those of the proximal end of the humerus the tibial plateau and the bodies of the vertebrae There can be little doubt that skeletal changes which predispose to fracture are generalized throughout the body

Loss of bone tissue (osteopenia) is commonly believed to be associated with fracture *indirect* evidence for this association is abundant The incidence of osteopenia is higher in women than in men (COOKE 1955) Although rarely seen below age 50 it is increasingly common above this age The exact incidence of osteopenia is unknown owing in part to a lack of accepted standards of definition and measurement A progressive decrease of the total skeletal mass with advancing age has been described in a large series of human skeletons (INGALLS 1931) Other authors have described a decrease with age of the weight per unit volume of bone (TROTTER et al 1960 LINDAHL and LINDGREN 1962) and in a micro radiographic study of cortical bone from the human femur JOWSEY (1960) found increasing porosity in the aged A *direct* association between osteopenia and fracture of the proximal end of the femur was claimed by STEVENS et al (1962) based upon histologic evaluation of iliac bone biopsy and standardized radiographical measurements in fracture patient URIST (1960) found a higher incidence of compression fracture of vertebrae and ballooning of intervertebral discs in women with fracture of the proximal end of the femur than in controls

Changes in the quality of bone tissue have received relatively little attention It is well known that bone in children is more resilient than in adults as evidenced by the occurrence of greenstick fractures but it remains only a clinical impression that bone in the elderly is more fragile An example of an alteration in bone quality is furnished by fracture of the neck of the femur following radiotherapy to the pelvis Such fractures are distinguished by their gradual onset over a period of days or weeks and seem to have some features in common with fractures occurring in osteomalacia Recent observations on an association between certain skin changes and osteopenia may have some significance with regard to changes in the quality of bone (McCONKEY et al 1962)

Evidence strongly suggests that fracture of the proximal end of the femur in the absence of obvious local disease is a sign of disturbed skeletal metabolism more prominent when the fracture is caused by moderate rather than severe trauma The evidence that this generalized skeletal disorder can be entirely described by the term osteopenia is by no means conclusive and for the purpose of this discussion it will be termed progressive bone fragility

a *Etiology of progressive bone fragility*

Previous thoughts on the etiology of age changes in bone are partly obscured by the tacit assumption that fracture is a sign of osteopenia. COOPER (1824) and subsequently ALBRIGHT and REIFENSTEIN (1948) believed that osteopenia was due to deficient bone formation. The latter authors showed that *hormonal factors* may be operative and they also showed that *pregnancy* and *lactation* may cause large calcium deficits. Against this background it is probably significant that in this study neither parity nor age at menopause were found to have any relationship to the occurrence of fracture of the proximal end of the femur.

Nutritional factors in the etiology of osteopenia have been considered by a number of authors (for references see NORDIN 1960 and WHEDON, 1960) and occasional reports exist on the association of nutritional deficiency with fracture of the proximal end of the femur (RENO and BURLINGTON 1958, HOHLE 1952). While nutritional factors were only indirectly considered in this study it is striking that the general pattern of sex, age and moderate trauma is the same in this material as in those of COOPER (1824) and BRUNS (1882) at a time when diets were probably deficient by today's standard. In as much as this material is interpreted to show that fracture of the proximal end of the femur is a late sign of a generalized skeletal disease, it is difficult to attach much etiologic importance to poor eating habits in elderly people.

Seasonal variation in the birth dates of patients with fracture of the proximal end of the femur was observed in this study. This suggests a possibility that influences operating during prenatal life or infancy may have etiologic significance with regard to skeletal fragility in the aged. Such influences may be, e.g., hormonal, alimentary or climatic in nature. Perhaps it would be profitable to study whether variations in the intake of trace elements such as copper and manganese during early life have any influence upon skeletal metabolism in adult life (for references see ASLING and HURLEY 1963).

Heredity was suggested by FINLEY (1956) as a possible etiologic factor in osteopenia of old age and BUCKWALTER et al. (1957) and THORSOE (1960) found an association between blood group A and the occurrence of fracture of the femoral neck. In this series alone no association was found but when the three materials were combined a significant association was found suggesting that hereditary factors may have a bearing on liability to this type of fracture.

Another factor indicating the importance of heredity is the *racial* difference in fracture incidence. GYEPES et al. (1962) in an American hospital

found fractures of the proximal end of the femur to be uncommon in Negroes The finding in this study that the incidence of cervical fractures is twice as high in Sweden as in Great Britain may indicate a hereditary factor but does not exclude environmental or nutritional factors Further studies of geographic differences in fracture incidence may perhaps unearth presently unrecognized factors in the etiology of fracture of the proximal end of the femur

B ETIOLOGIC CLASSIFICATION OF FRACTURE OF THE PROXIMAL END OF THE FEMUR

Anatomical classification of fractures of the proximal end of the femur are useful from a mechanical point of view in the selection of methods of treatment and probably in assessing prognosis with regard to healing of the fracture An anatomical classification is not sufficient however for evaluation of the prognosis quoad vitam, or for prediction of long term functional results (ALFFRAM 1961) Such evaluation is increasingly important now that the choice of therapy is wider than in Cooper's day or even a decade ago A more precise classification is needed for other reasons too During the course of this study it became embarrassingly apparent how difficult it can be to compare clinical material from different centers because of lack of definition and differences in composition This has probably tended to hamper progress in evaluation of various types of treatment, for example open vs closed methods in the treatment of trochanteric fractures This lack of a suitable classification is also felt in studies aimed at prevention of fracture of the proximal end of the femur

In his daily routine a surgeon subconsciously evaluates a patient not only with regard to the anatomical type of fracture but also to age degree of trauma associated with the fracture coexisting disease and bone fragility In doing this he employs important etiologic factors as his parameters The purpose of this work has been to make an analysis of these parameters The immediate difficulty in such an analysis is that the parameters tend to overlap in most patients with fracture of the upper part of the femur With the aid of a Venn diagram (Figure 19 FEINSTEIN 1963) an attempt has been made to schematically evaluate the various types of overlap to attach frequency values to them and to propose an etiologic classification of fractures of the proximal end of the femur

For the purpose of this discussion *disease* means every known abnormality except those described below under age *Trauma* means a definite accident

Table 14 *Analysis of Group F in Fig 20 and Table 13 with regard to sex trauma and fracture type*

Sex	Women				Men			
Trauma	Moderate		Severe		Moderate		Severe	
Fracture type	Cervical (1)	Trochanteric (2)	Cervical (3)	Trochanteric (4)	Cervical (5)	Trochanteric (6)	Cervical (7)	Trochanteric (8)
No of cases	199	121	26	23	30	28	20	15
Mean age	80 6	81 4	78 3	77 3	79 7	80 7	75 7	75 7
Mortality within 3 months (per cent)	19	22	15	13	27	21	0	6 7

V GENERAL SUMMARY[1]

METHODS

The 1 664 fractures of the proximal end of the femur occurring in the 209 473 population of the city of Malmo from 1949 through 1961 formed the material of this investigation

Accurate census data permitted evaluation of age and sex incidence of the fractures classified by anatomical type and degree of associated trauma Case records and re examination in 1960 of 98 per cent of those surviving after fractures sustained from 1949 through 1958, furnished information concerning mortality other fractures and associated medical conditions

RESULTS

A *Radiographically Apparent Lesions* Nineteen fractures associated with such lesions were excluded from the study but considered in the General Discussion

B *Types of Fracture* In women cervical fracture was twice as common as trochanteric fracture while in men these main types were equally common In women three of four cervical fractures were subcapital and one transcervical while in men these types were evenly distributed In both sexes one fourth of the cervical fractures were stable

C *Sex and Age Distribution* The mean age was 73 0 $\pm$ 0 33 years in women and 69 0 $\pm$ 0 70 years in men with 86 per cent over 60 years of age After the adjustment for differences in the age distribution of the population at risk, fracture of the proximal end of the femur was 2 4 times more common in women than in men This ratio did not change appreciably from age 50 through 80 even though the incidence approximately doubled with each five year increment in age

D *Types of Trauma* Spontaneous fracture was recorded in 18 cases in Series A 11 of which had either a radiographically apparent lesion or a history of radiotherapy for a pelvic malignancy In women moderate trauma was nine times more common than severe trauma while in men the two types were equally common The proportion of moderate trauma increased with age more in men than in women The pattern of trauma did not differ between cervical and trochanteric or unstable and stable cervical fractures Subcapital fracture was seen more often after moderate trauma than was transcervical fracture

[1] Alphabetical subheadings correspond to those under III Results

E *Mortality* The three month age adjusted mortality rate was unrelated to sex main type of fracture or method of treatment (traction or nailing), but was lower after severe than after moderate trauma indicating that main factors affecting mortality were age and the general condition of the patient prior to fracture

F *Fracture Incidence* Over the thirteen year period the annual number of fractures increased due to age shifts in the population and an increased incidence of trochanteric fractures Cervical fractures were two times more common in Sweden than in Great Britain whereas there was no difference in the incidence of trochanteric fractures

G *Other Fractures* Women with a fracture of the distal end of the forearm (Colles fracture) are more liable to suffer fracture of the proximal end of the femur than women without a forearm fracture

H *Associated Conditions* The incidence of diabetes mellitus was higher than normal in female fracture patients In hemiplegia and poliomyelitis the fracture occurred more often in the paretic leg than in the normal leg The ratio of moderate to severe trauma was higher in patients suffering from disease than in healthy patients Neither parity nor the age at menopause had any effect upon fracture liability

I *Seasonal Variation of Birth Dates* The seasonal variation in birth dates of female patients with fracture due to moderate trauma differed from that of the general population

J *Blood Groups* Fracture patients had a higher than normal incidence of blood group A

INTERPRETATIONS

The association of the spontaneous fractures with radiographically apparent bone disease and previous radiotherapy and the tendency of fractures associated with severe trauma to occur in young and healthy individuals suggested that the degree of trauma as evaluated from the case histories was a valid indicator of skeletal fragility On this basis the results of this investigation are interpreted to show that skeletal fragility is a predominant factor in the etiology of fracture of the proximal end of the femur that bone fragility is more common in women than in men and that it increases sharply with age Certain medical conditions may increase bone fragility either locally or generally in the skeleton In most cases the cause of the fragility is not known This study has shown that hereditary as well as environmental factors may be significant

CONCLUSION

Fracture of the proximal end of the femur is a result of the interplay of three factors — trauma disease and non specific skeletal fragility associated with aging Appreciation of the relative significance of each of these factors in the etiology of the various anatomical types of this fracture should lead to a better understanding of this condition Such understanding may in turn lead to improvements in methods of treatment and hopefully to prevention of this disease

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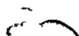
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MALMÖ 1964
SYDSVENSKA DAGBLADETS AB
64 395

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM nr 66

FROM THE ORTHOPAEDIC RESEARCH LABORATORIES (HEAD: GÖRAN C. H BAUER M D)
AND THE ORTHOPAEDIC CLINIC (HEAD SOPHUS v. ROSEN M D)
AND THE ROENTGEN DIAGNOSTIC DEPARTMENT (HEAD SÖLVE WELIN M.D)
MALMÖ GENERAL HOSPITAL, UNIVERSITY OF LUND MALMÖ SWEDEN

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CONTENTS

Translated by
Mr L James Brown

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Financial support was obtained from grants given to Professor Goran Bauer from the National Institutes of Health Bethesda Grant No DE 1432 and the International Atomic Energy Agency, Vienna and to the author from Ulla and Gustaf af Ugglas Foundation Stockholm Herman Järnhardts Foundation Malmo and the Faculty of Medicine, the University of Lund

I INTRODUCTION

On October 11, 1859 Fock in Magdeburg resected the head and neck of the femur in a case of osteoarthritis of the hip (coxarthrosis) This was the first recorded operative intervention for this condition Now a century later operations for coxarthrosis are standard procedures in orthopaedic surgery Opinions as to the merit of different operations vary widely leading orthopaedic surgeons or schools may advocate operations which are in principle quite different for one and the same patient In few fields of surgery has there occurred such a rapid rise and fall of new or modified operative methods

A survey of the continuing discussion of the treatment of coxarthrosis revealed at least one fundamental difficulty inherent in the choice of method there is little knowledge of the natural history of coxarthrosis The literature does not contain comparisons of results obtained in operated and unoperated series objective comparisons of preoperative with post operative conditions in well defined groups of patients are virtually non existent

In this investigation coxarthrosis was examined as a disease entity The stable homogenous population centralized hospital system and availability of census data in the city of Malmo provide good conditions for such a study

To establish radiographic criteria cases diagnosed on this basis in 1951 were after examined in 1962 and the significance of minor joint changes determined

Using these criteria the incidence of primary coxarthrosis was calculated over a five year period 1950 to 1954 permitting prediction of future trends in incidence in an aging population

Changes in the course of the disease evident on clinical an examination of a non operated material after 10 years permitte of certain aspects of the natural history and prognosis of coxarthrosis

Table 1 *Secondary Coxarthrosis*[1]

- Congenital
  - Anomalies of pelvis and femur
  - Congenital dislocation of the hip (7)
  - Alkaptonuria
  - Hemophilia
- Acquired
  - Developmental
    - Perthes disease (3)
    - Slipped epiphysis (2)
    - Osteochondritis dissecans
    - Coxa vara
  - Infection (2)
    - Tuberculosis
    - Pyogenic arthritis
  - Rheumatic fever (1)
  - Rheumatoid arthritis
  - Metabolic
    - Rickets
    - Gout
    - Paget's disease
  - Trauma (3)
    - Fracture
    - Dislocation
  - Neoplastic
    - Chondromatosis
    - Tumors of bone and soft tissue
  - Neuropathy
    - Syphilis
    - Syringomyelia
    - Leprosy

1 Series A — Radiographic Diagnosis and Definition of Coxarthrosis

The records of the MGH Roentgen diagnostic Department were reviewed to collect all cases attending the Orthopaedic Clinic during 1951 in which coxarthrosis had been diagnosed radiographically (Table 2)

Series A comprised 214 patients divided into two major groups (Table 3) Series A^+ those with structural and/or joint space changes and Series A^- those without structural or joint space changes Series A^- was then divided into 3 subgroups according to the osteophyte index (Table 10)

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[1] Rheumatoid arthritis and fracture of the neck of the femur were not included in this investigation
Coxarthrosis with subluxation or acetabular protrusion was regarded as primary
Figures within brackets denote number of patients (Series C)

II MATERIAL AND METHODS

A POPULATION

The city of Malmö situated in the southern part of Sweden has a population of 225 660 (Census January 1960) Detailed census data are recorded by city authorities about such items as age sex and migration and predicted census figures have been published Study of migration data by ALFFRAM (1964) has confirmed the stability of the older age groups in this population The city is served by one general hospital MGH (1585 beds) with a 156 bed orthopaedic department one mental hospital MMH (675 beds) and one geriatric hospital GH (600 beds)

The centralized hospital system, a stable population, and the availability of detailed census data have made Malmö an ideal site for the epidemiologic study of diseases such as arteriosclerotic heart disease (BIORCK et al 1957) and fracture of the proximal end of the femur (ALFFRAM 1964) The World Health Organization has recently selected Malmö as the site for an investigation of heart disease

B SELECTION OF PROBANDS

Coxarthrosis implies a chronic disease with change in the structure and function of the hip joint

For the purpose of this investigation a distinction was made between *primary* and *secondary* coxarthrosis with the latter term referring to cases in which the disease was associated with a predisposing condition (Table 1)

In view of the relation between luxation and subluxation (ANDREN 1962) coxarthrosis due to subluxation should be ascribed to the secondary group But in practice it proved much easier to distinguish between luxation and subluxation in advanced coxarthrosis than between subluxation and normal All cases of coxarthrosis with subluxation were therefore regarded as primary

Series A (214 patients) was chosen to allow evaluation of radiographic criteria for the diagnosis of coxarthrosis Using these criteria Series B (258 patients) was selected to permit estimation of incidence of primary coxarthrosis The natural history of coxarthrosis over a ten year period was studied in Series C (168 patients)

Table 3 *Radiographic material from 1951*

Radiographic appearance	Number of patients			
	Total		After examined	
Series A+ Structural and/or joint space changes	27		27	
Series A− No structural or joint space changes	187		86	
Osteophyte index 2		20		17
index 1		84		42
index 0		83		27
Total	214		113	

All cases in Series A+ and samples of those in the subgroups of Series A− were after examined clinically and radiographically during 1962. The samples were representative of the original Series A− groups by age and sex (Table 4).

Table 4 *Patients grouped according to age and osteophyte index*

Osteophyte	Total		After examined	
	Number of patients	Age 1962 Mean S E M	Number of patients	Age 1962 Mean S E M
Index 2				
Male	16	63 8±2 85	14	64 9±2 67
Female	4	73 8±6 23	3	69 0±5 69
Index 1				
Male	45	61 4±1 59	23	59 2±1 90
Female	39	58 4±1 62	19	58 6±2 50
Index 0				
Male	31	54 7±2 01	9	57 9±2 5[illegible]
Female	52	58 7±1 53	18	61 [illegible]±2 28

2 Series B — Incidence of Primary Coxarthrosis

This series included all cases (258 patients) of primary coxarthrosis with structural and/or joint space changes found by review of records at MGH, MMH and GH from the years 1950—1954. Cases of secondary coxarthrosis were excluded on the basis of clinical records and radiographs.

Table 2. *Radiographic material from period 1950—1954*

	1950	1951	1952	1953	1954	1950—1954
Patients registered as coxarthrosis						
Total	759	895	883	708	651	3 896
Referred from the Orthopaedic Clinic	250	329	322	228	214	1 343
Referred from the Orthopaedic Clinic and living in Malmö at time of after examination	—	214	—	—	—	—
Patients *with structural and/or joint space changes* referred from the Orthopaedic Clinic	33	43	36	38	39	189
Patients rediagnosed radiographically	—	1	3	8	9	21
Patients diagnosed for first time radiographically	33	42	33	30	30	168
Patients dead at time of after examination	11	15	13	2+1[1]	9	50+1[1]
Patients alive at time of after examination	22	27	20	27	21	117
Patients operated and alive at time of after examination	3	6	4	7	6	26
Patients non operated and alive at time of after examination	19	21	16	20	15	91

[1] Emigrated

Table 5 [illegible]

[illegible] (19[illegible] a 19[illegible])	[illegible] (195[illegible]) [illegible] et al (1957)	[illegible] (19[illegible])
1 severe, lack of sleep	1 severe, lack of sleep	0 douleur très vive et continue
2 severe when walking, unable to work	2 severe when walking, unable to do light work	1 douleur très vive empêchant le sommeil
3 moderate, able to do light work	3 moderate, able to do light work	2 douleurs vives à la marche empêchant toute activité
4 pain after effort relieved by rest	4 pain after effort relieved by rest	3 douleur vive mais permettant une activité limitée
5 light and intermittent, able to do full work	5 light and intermittent, able to do full work	4 douleurs seulement après la marche disparaissant rapidement par le repos
6 absent	6 absent	5 douleurs très légères et intermittentes n'empêchant pas une activité normale
		6 indolence complète

3 Series C — The Natural History of Primary and Secondary Coxarthrosis

This series included all cases (168 patients) who attended the Orthopaedic Clinic 1950—1954, because of hip complaints, and who had radiographically verified structural and/or joint space changes indicative of primary or secondary coxarthrosis (Table 2) Surviving patients were reexamined clinically and radiographically during 1962 Fourteen of the coxarthrotic patients in Series C were studied with external counting of Sr^{85} (DANIELSSON et al 1964) Values are given in Table 35

C CLINICAL EVALUATION OF PROBANDS

The probands were evaluated on the basis of clinical and radiographic examinations The clinical evaluation was made with regard to pain, range of motion and restriction of function

1 Pain

Pain is the chief complaint in coxarthrosis Earlier methods of grading pain in this disease are listed in Table 5 None of these systems made a distinction between types of pain, *e g* starting walking or resting pain and for this reason they were not regarded as suitable

The method of grading pain used in this study is shown in Table 6, in which the sum of points from 0 to 5 gives a numerical value for the severity of pain

2 Range of Motion

JUDET and JUDET (1952) and STINCHFIELD et al (1957) graded the range of motion of the hip according to the sum of degrees of motion in the different planes MERLE D'AUBIGNE and CHABROL (1952) graded the range of motion according to flexion and abduction only FERGUSON and HOWORTH (1931) and HALLOCK (1939) multiplied the angles of motion by factors which resulted in an index of 100 for a normal hip (*i e* flexion and abduction ×0 4, plus adduction and internal rotation ×0 2 plus external rotation and extension ×0 1 GADE (1947) stated that the usefulness of the range of motion varied according to the plane considered (external rotation more useful than internal abduction more useful than adduction) and that the first degrees of motion in each plane were of the most significance He therefore introduced a modified index which was adopted by SHEPHERD (1954 a 1954 b 1960)

In this study Gade s system was employed with the exception that measurements of rotation were made with the hip flexed preferably 90° and not with the hip extended

SPENCE 1958) and permitted separate evaluation of various aspects of restriction of function SHEPHERD's scheme was therefore adopted for this investigation (Table 8) A few modifications and changes in definition (as indicated in Table 8) were made in order to permit more stringent classification

Advanced age and coexisting disease might have contributed to restriction of function in some cases (Table 9)

Table 9 *Restriction of function in nine patients with coexisting condition*

Coexisting condition	Restriction of function		
	Mild	Moderate	Severe
Possibly contributory Slight cardiac symptom Dizziness *Presenility* Arthrodesis of contralateral knee Below knee amputation of contralateral limb	1	1	3
Certainly contributory Blindness Neural muscular athrophy of lower legs Postoperative lymphoedema of ipsilateral limb Above knee amputation of contralateral limb	—	1	3

D RADIOGRAPHIC EVALUATION OF PROBANDS[1]

Coxarthrosis has been classified using such parameters as the inclination of the neck of the femur shape of the acetabulum, depth of the acetabulum, and the shape and size of the head of the femur (WIBERG 1939 a 1939 b FRANCON 1956) Some of the difficulties in using such measurements have been pointed out by HERMODSSON (1944) and FRANCON (1956) WIBERG (1939 a 1939 b) has described the types and localisation of osteophytes as well as the anatomical explanation of the 'double floor' appearance of the acetabulum

[1] *Radiograps interpreted in cooperation with Dr B Frost (Roentgen diagnostic Department Malmo General Hospital)*

C[illegible] IN EVALUATION OF COXARTHROSIS

L hme mous f arthrose Act rthop ca d Suppl 66, 1964

RESTRICTION OF FUNCTION

		Ind
Limp	N	0
	Yes	1
Trend l burg test	N g t	0
	Questionabl	1
	Pos ti	2
Walking and	U lded	0
	R quire on sti k	1
	Requires two ti k	3
	Requires two trestles	4
D tance w lk d with t p in	>1500 m	0
	400—1500 m	1
	100—400 m	
	1 —100 m	3
	N t t ll	4
Completely bedridd n		10
P tt g wn hoe d sock	Yes	0
	W th difficul y	1
	N	2
Stair climbing	Yes	0
	W th difficulty	1
	N	2
T il t	Yes	0
	W th difficul y	1
	N	2
B thi g	Yes	0
	W th difficul y	1
	N	2
W k and ctivit es	H vy phy l	0
	Moderate I	1
	Light II	
	Slight III	3
	N	4

I Moder t g fa tory w k, all w k in larg household (≥ 4 pe so) ll w k in mall h usehold (< 4 persons) + tr w k

II Light, g all w k in small h usehold light manual labour

III Sl ght g all w k in mall h useh ld cept cl ning cl rical w k

Mild	= 0—6
Moderat	= 7—12
Se	= 13—28

RADIOGRAPHIC SEVERITY

		Ind x
Ost ophyt	Non	0
	V si bl on pol (perio or inf rior) f the j nt	1
	V sibl both poles	2
	Bulky both poles	3
J int pace	N rmal	0
	N rr wed b t larg than half n rmal width	1
	Smaller tha half n rmal width	2
	Eff ced over m re than half fem al contour	3
Stru tur	Normal	0
	Hyperdensity or cysts in caput or cetabulum	1
	Hyperden ty or cysts in put nd cetabul m	2
	Gross l destro ed	3
Asso iated m m lies	N	0
	Doubl floo	1

RADIOGRAPHIC LOCALISATION

Lateral
Medial
Mi ed

KEY TO CRITERIA

D n Isson, L, G r I den e d p

PAIN

		Ind x
St rting pain	No	0
	Yes	1
Pain when walki g	No	0
	Slight	1
	Severe	2
R ting pain	N	0
	After walking dis ppears during r t	1
	Spont eo s	2

Ex ellent = 0–1
Good =
F ir = 3
Poo = 4–5

RANGE OF MOTION

		Ind
Flexi	180°–13 multiply by 0 6	–
	135 – 90° multiply by 0 4	–
	90°– 30 m ltiply by 0 1	–
Abd tion	0 – 15 mult ply by 0 6	–
	15 – 30° multiply by 0 4	–
	30°– 60 multiply by 0 1	–
Ext rnal rot t n	0°– 15 multiply by 0 3	–
	30 – 80 multiply by 0 1	–
Add t n	m ltiply by 0,2	–
Int n l rotati n	mult ply by 0 2	–

Excell nt ≥ 50
Good = 49– 0
F ir = 19–10
P < 10

Val

Distanc

Completely

Putting on

Stair climbing

Toilet

B thing

Work and acti ities

I Moderate e g fa (≥ 4 persons), al sons) + extra wor

II Light, g all wor

III Slight, g all w clerical work.

Mild = 0 6
Moderate = 7 1.
Se ere = 13 23

HERM[…]SON (1944 1948) cla[ss]ed coxarthrosis as upper or medial accord[ing to the site] of narrowing of the joint space. LEQUESNE (1958) [divided the upper type] into 4 subgroups (polaire super[…] and polaire interne).

[…]hanges

H[…] introduced a method for esti[mating …]ges based upon presence of o[…]ange and double floor. Th[…]nt investigation is shown in T[…]

ERRATA

Page	Line		
31	8 from below	56	should read 51
32	10	forty	forty-one
32	11	56	51
32	19	31	36
3[…]	3	31	35 per cent
41 table	21	always	completely
41	22 bottom row	22	14
42	23 top row	2	9
47 line	7	female	male
58	[…]	13	33
58	8 from below	[…]val u[…]	[…]varu[…]
8[…]	5	49	51
85	7 and 9	medial	lateral
93 table 32	1 line row	No pain	pain 18
110	3	Kh	Kh+

[…]aphic severity

[…]everity	Index
	0
[…] one pole (superior […]) of the joint	1
[…] both poles	2
[…] both poles	3
	0
[…]ed but larger than […]rmal width	1
[…]r than half normal width	2
[…]ed over more than half […]cal contour	3
[…]mal	0
[…]perdensity or cysts in caput […] acetabulum	1
[…]perdensity or cysts in caput […]d acetabulum	2
[…]rossly destroyed	3
Associated a[…] None	0
Double floor	1

2 Localisation of Radiographic Changes

In the present study HERMODSSON's and LEQUESNE's systems were modified and radiographic changes were classified as *lateral*, *medial* or *mixed* in type.

The following definitions were used:

Lateral: Joint space changes mainly or solely in the upper lateral part of the joint.

III RESULTS

A RADIOGRAPHIC DIAGNOSIS AND DEFINITION OF COXARTHROSIS

1 Previous Studies

The presence of osteophytes originating from the femoral head or from the acetabulum has been considered a sign of coxarthrosis (HERMODSSON 1947) BRAILSFORD (1952) has challenged this view, stating that such small radiographic changes are not signs of coxarthrosis JAQUELINE et al (1950) and JACQUELINE and VERAGUTH (1954) have stated that osteophytes are probably part of the physiological process of aging

It was therefore considered desirable to ascertain what radiographic changes justify a diagnosis of coxarthrosis

2 Present Study

a) *Series 1+*

This series included all patients with structural and/or joint space changes in 1951 The 27 surviving patients (6 males and 21 females) in this group were examined clinically and radiographically in 1962 In all cases such structural and/or joint space changes persisted in 1962 The range of motion was invariably reduced (Table 34)

b) *Series A−*

This series included all patients in whom the diagnosis of coxarthrosis in 1951 had been based upon the presence of osteophytes without structural or joint space changes Samples of three subgroups selected according to their osteophyte index were examined in 1962 The 5 patients in Series A− who were not clinically normal in 1962 are listed in Table 33

Osteophyte Index 2

None of the 17 patients (14 males and 3 females) examined in 1962 had developed structural or joint space changes All were free from pain and all except one (1390) had a normal range of motion The index for restriction of function was 4 or less

Osteophyte Index 1

Of the 42 patients (23 males and 19 females) examined only one (1868) had developed joint space changes This patient also had pain and a decreased range of motion Two (1377 and 1503) patients had a decreased

Medial Joint space changes mainly or solely in the central medial part of the joint

Mixed Changes not falling with certainty in either of the two above mentioned groups

Fig 16 19 and 23 illustrate typical lateral and medial structural changes

3 Course between 1950—1954 and 1962

This was evaluated by comparing antero posterior radiographs of the pelvis taken at the time of after examination in 1962, with those taken in 1950—1954

E STATISTICAL CONNOTATION[1]

Conventional statistical methods were used (Bailey 1961)

Statistical significance was described as follows

$P > 0\ 05$ = not significant

$0\ 05 > P > 0\ 01$ = almost significant*

$0\ 01 > P > 0\ 001$ = significant**

$0\ 001 > P$ = highly significant***

S E M = Standard error of the mean

[1] Data treated statistically under supervision of Professor C E Quensel Institute of Statistic University of Lund

Table 1? *Age and sex distribution of osteophyte indexes (Series 1-)*

O teo phyte	Number of patients		Age						Mean age difference Female minus Male
	Male	Female	Male		Female		Total		
			Mean	S E M	Mean	S E M	Mean	S E M	
Index 2	16	4	52 8	± 2 85	62 8	± 6 23	54 8	± 2 68	+ 10 0
Index 1	45	39	50 4	± 1 59	47 4	± 1 62	49 0	± 1 13	— 2 9
Index 0	31	5?	43 7	± 2 01	47 7	± 1 53	46 2	± 1 2?	— 4 1

range of motion without pain The index for restriction of function was 3 or less except for one (1503) patient with an index of 24

Osteophyte Index 0

None of the 27 patients (9 males and 18 females) in this group had developed *structural or joint space changes by 1962 All were free of pain* and with the exception of one (1142) had a normal range of motion The index for restriction of function was 3 or less

Osteophyte Index 1951 compared with Osteophyte Index 1962

Changes in osteophyte index in Series A⁻ over the eleven year period are shown in Table 11 The occurrence of osteophytic changes in previously normal hips is apparent

Table 11 *Hips with osteophyte index 2 1 or 0 1951 and 1962*

Number of hips 1951		Number of hips 1962		
		Osteophyte index 2	index 1	index 0
Osteophyte index 2	21	19	1	1
index 1	74	12	52	10
index 0	75	2	25	48
Total	170[1]	33	78	59

[1] Two patients examined on one side only

Table 12 demonstrates the direct relation between osteophyte index and mean age in both sexes and that index 2 and index 1 were more common in males *After correction for age and sex distribution, osteophytes* were more commonly seen in males

3 Comments

Patients who had radiographic structural and/or joint space changes in 1951 had such changes at examination in 1962 Of the 86 patients in whom a radiographic diagnosis of coxarthrosis had been made in 1951 despite the absence of structural or joint space changes, only one had developed such changes by 1962 In most cases the diagnosis of coxarthrosis had been based upon the demonstration of osteophytic changes alone

Hip joints with osteophytes but without structural or joint space changes were not and did not become arthrotic (Fig 9, 10 11, 12)

B INCIDENCE OF PRIMARY COXARTHROSIS

1 Previous Studies

The reported incidence of coxarthrosis varies widely depending upon the method of selection of patients and the diagnostic criteria HOLLANDER (1957) claimed that 90 to 95 per cent of all people above 60 years of age have had arthrotic pain SILVERSTEIN (1961) believed that only 5 to 10 per cent of those with arthrosis ever sought medical advice FRANCON (1956) was of the opinion that coxarthrosis is extremely common

HERMODSSON (1947) reported radiographic evidence of coxarthrosis in 30 of 100 patients above 50 years of age who had subjectively normal hips KELLGREN (1961) and KELLGREN and LAWRENCE (1961) noted such changes in 20 per cent of patients above 55 years The figures given above include both primary and secondary coxarthrosis

No data are available on the age and sex distribution and mortality of primary coxarthrosis

2 Present Study

Series B included all cases of primary coxarthrosis diagnosed radiographically in Malmo during the five year period 1950—1954 Table 13 shows the number of cases by age sex and source—whether referred from the Orthopaedic Clinic or other clinics and private physicians Study of the mortality and age and sex specific incidence in this series permitted a prediction of the number of cases of primary coxarthrosis in the population of Malmo in 1960

a) *Mortality*

The observed mortality of Series B over the ten year period prior to the after examination was compared with that in sex and age matched groups of the general population of Malmo The observed and expected numbers of deaths in series B were the same (101 deaths in 258 patients)

b) *Annual Incidence*

The system of registering patients according to diagnosis was begun at the MGH Roentgen diagnostic Department in 1950 Some cases recorded from 1950 to 1954 might have been diagnosed prior to that time as well but were probably few

4 Summary

Of 214 patients referred from the Orthopaedic Clinic in 1951 in whom a diagnosis of coxarthrosis had been made radiographically 27 had structural and/or joint space changes while the radiographic findings in the remaining 187 were confined to osteophytic changes

The small group of 27 patients with structural and/or joint space changes when examined in 1962 showed the same radiographic changes and were clinically not normal

The large group of 187 labelled "coxarthrosis" on the basis of osteophytic changes alone was divided into 3 subgroups according to the extent of such changes Eighty six patients representing samples of each subgroup were examined radiographically and clinically in 1962 Only one of these patients had developed joint space changes and was clinically not normal

Hip joints with osteophytes but without structural or joint space changes were not, and did not become arthrotic during the 11 year period A diagnosis of coxarthrosis must therefore be based upon radiographic structural or joint space changes and not on osteophytes alone

Table 14 *Patients with primary coxarthrosis in period 1950—1954*

	Diagnosed for first time	Diagnosed also before in period
1950	52	1
1951	52	8
1952	59	7
1953	47	9
1954	48	8
Total	258	33

the period 1950—1954 was interpolated from census data compiled in 1950 and 1960. The age and sex specific incidence calculated on this basis is shown in Table 15 and Fig. 1.

Table 15 *Patients with primary coxarthrosis diagnosed for first time in period 1950—1954*

Age groups	Absolute number		Number per 10 000 inhabitants		
	Male	Female	Male	Female	Total
35—39	2	3	0.5	0.7	0.6
40—44	2	1	0.5	0.2	0.4
45—49	2	8	0.5	2.1	1.3
50—54	7	14	2.4	4.2	3.4
55—59	16	18	6.9	6.4	6.6
60—64	25	19	12.5	7.6	9.8
65—69	26	26	15.7	12.2	13.7
70—74	28	27	23.9	16.5	19.5
75—79	11	13	15.6	13.4	
80—84	5	2	16.1	4.1	12.0
85—89	—	3	—	15.7	
>65	70	71	17.6	13.0	15.0
Total	124	134			

The incidence of *diagnosed* primary coxarthrosis increased with age up to 75 years. Possibly the *true* incidence continues to increase above this age but this was not reflected here probably because old people are not so likely to seek advice or be examined for this disease. There was no significant difference in incidence between the sexes.

Table 13 *Patients with primary coxarthrosis in period 1950—1954 (Series B)*

Age at first diagnosis	No. of patient				No. of deaths				Mortality rate per 1000	
	Male		Female		Male		Female		Male	Fem
	a	b	a	b	a	b	a	b		
Diagnosed for first time in period 1950—1954										
<40	1	1	—	3	—	—	—	—	30	23
40—44	2	—	—	1	—	—	—	—	46	36
45—49	1	1	6	2	—	—	—	—	73	56
50—54	4	3	8	6	—	—	—	1	118	87
55—59	6	10	15	3	1	1	1	1	182	141
60—64	17	8	14	3	4	4	2	—	280	234
65—69	15	11	14	12	5	3	9	6	417	375
70—74	20	8	12	15	11	6	5	13	598	564
75—79	3	8	2	11	3	8	1	8	784	756
80—84	2	3	2	—	2	3	2	—	918	896
85—89	—	—	1	2	—	—	1	2	1000	1000
Total	71	53	74	60	24	25	21	31		
No. of expected death					29	23	23	26		
Diagnosed also before in period 1950—1954										
40—44	1	1	—	—	—	—	—	—	—	—
45—49	—	—	—	1	—	—	—	—	—	—
50—54	1	—	2	—	—	—	—	—	—	—
55—59	—	1	1	—	—	1	—	—	—	—
60—64	3	2	—	1	—	—	—	—	—	—
65—69	3	3	—	—	—	1	—	—	—	—
70—74	2	3	—	5	2	1	—	5	—	—
75—79	1	—	—	2	—	—	—	2	—	—
Total	11	10	3	9	2	3	—	7	—	—
No. of expected deaths					4	4	0.3	5	—	—

a) = Referred from the Orthopaedic Clinic.
b) = Referred from other clinics or private physician

The number of cases of primary coxarthrosis diagnosed during each of these five years ranged from 47 to 59 with a mean of 52 (Table 14)

c) *Age and Sex Specific Incidence*

In order to calculate the incidence of primary coxarthrosis per 10 000 inhabitants in various age groups the mean population of Malmö during

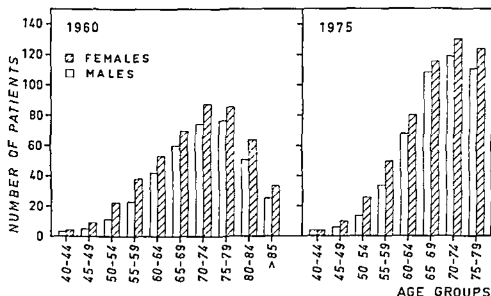


Fig °
Calculated number of patients with primary coxarthrosis in Malmo in 1960 and 1975 clas ified according to age and sex

KELLGREN s figure of 20 per cent the incidence of primary coxarthrosis above age 55 in this study was only 1 6 per cent His higher figure resulted from use of the conventional radiographic definition of coxarthrosis it was apparent from a study of series A that if all radiographically evident changes were accepted as signs of coxarthrosis the incidence would be very high

The average annual incidence of radiographically diagnosed primary coxarthrosis in Malmo in 1950—1954 was 52 and may be compared with the average annual number (94) of fractures of the proximal end of the femur in the same period (ALFFRAM 1964)

4 Summary

Study of the age and ex distribution of primary coxarthrosis diagno ed during the five year period 1950—1954 gave values for the age and sex specific incidence of the disease in the city of Malmo In both sexes, the incidence of diagnosed primary coxarthrosis increased markedly with age up to 75 years and then dropped off somewhat possibly because old people

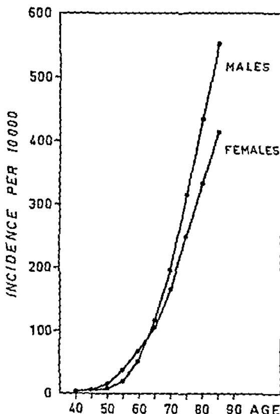


Fig 1
Total incidence of patients with primary coxarthrosis per 10 000 inhabitants cla sfie l according to age and ex

d) *Number of Patients with Primary Coxarthrosis in Malmo 1960 and 1975 (Fig 2 and 3)*

Age and ex specific incidence data were projected upon the population of Malmo and of Sweden to calculate the number of cases of primary coxarthrosis in 1960 and in 1975

In Malmo the number for 1960 was 831 (368 males and 463 females), and for the whole of Sweden 28 964 (14 226 males and 14 738 females) The expected number for 1975 is higher than for 1960 The increase will start in the 55—59 year group but be most marked in the high age classes

3 Comments

The high incidence in HERMODSSON s eries is explained by his acceptance of cases with osteophytic changes alone as coxarthrosis In only one of one hundred cases were there structural changes In comparison with

C NATURAL HISTORY OF COXARTHROSIS

1 Composition of material

Series C comprised the 168 patients who attended the Orthopaedic Clinic during 1950—1954 because of hip complaints and who had radiographically verified structural and/or joint space change (Table 2) It included both primary and secondary coxarthrosis All surviving patients of series C (with the exception of one who emigrated) were after examined clinically and radiographically during 1962 The after examined group consisted of 117 patients of whom 26 had undergone operation because of their disease

The average *age* of the patients in 1962 was 69 4 ± 0 91 years No age difference was noted between sexes or between operated and non operated groups In 1962 the age of patients with primary coxarthrosis was higher*** than that of patients with secondary coxarthrosis (70 6 ± 0 84 versus 62 2 ± 3 41) This reflects the lower age at onset of secondary coxarthrosis

a) *Sex Distribution*

Previous Studies

FISHER (1950) stated that coxarthrosis was more common in male FRANCON (1956) and PEARSON and RIDDELL (1962) reported that coxarthrosis was equally common in both sexes LEQUESNE (1958) found 40 per cent male and 60 per cent female In surgical series LLOYD ROBERTS (1955) reported equal distribution while ADAM and SPENCE (1958) found 30 per cent male and 70 per cent female

Present Study

Series C consisted of 168 patients (83 males and 85 females) At after examination in 1962 117 (56 males and 61 females) were still alive Coxarthrosis was equally common in both sexes at the time of diagnosis but with increasing age females predominated probably because of the higher mortality of males in high age groups

b) *Incidence of Secondary Coxarthrosis*

In series C 11 per cent had secondary coxarthrosis (11 males and 8 females) At after examination 1962 15 per cent (9 males and 8 females) had secondary coxarthrosis

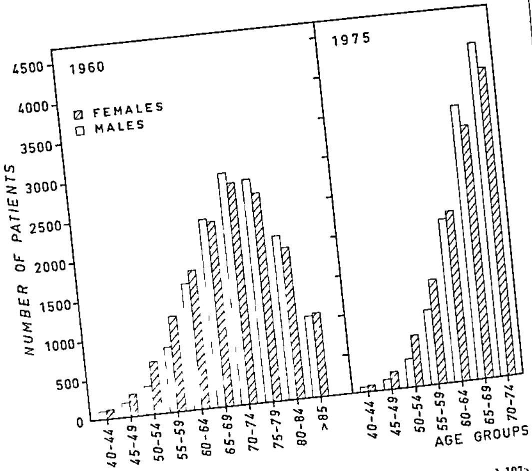


Fig 3
Calculated number of patients with primary coxarthrosis in Sweden in 1960 and 1975 classified according to age and sex

are not so likely to seek treatment The annual incidence of diagnosed primary coxarthrosis was about half of that of fracture of the proximal end of the femur

Forty per cent of the patients were dead within 10 years This mortality is the same as that for sex and age matched groups of the general population

Table 16 *Classification of published series according to etiology*

Etiology	Danielsson[1] (1964) 168 cases	De Sèze Lequesne Barbannaud (1962) 200 cases	Rufflé (1961) 1000 cases	Coste Laurent (1958) 317 cases	Lequesne (1958) 200 cases	Wiberg (1939 b) 257 cases
Acetabular dysplasia Subluxation Congenital dislocation	—	41 %	22 %	31 %	10 %	25.7 % (only subluxation)
Acetabular protrusion	5 %	5 %	20 %	7 %	7 %	—
Other causes	11 %	10 %	8 %	—	11 %	21 %
Primary coxarthrosis	—	44 %	50 %	—	42 %	53.3 %

[1] In the present investigation Primary coxarthrosis = Primary coxarthrosis, Subluxation and Acetabular protrusion
Secondary coxarthrosis = Other causes and Congenital dislocation

Table 17 *Localisation of pain*

	Localisation of initial pain			*Localisation of pain at after examination*		
Region	Male	Female	Total	Male	Female	Total
Greater trochanter	45	52	97	28	50	78
Groin	13	30	43	20	30	50
Knee	18	21	39	24	30	54
Total	76	103	179	72	110	182

On the basis of this interview the over all pattern of the localisation of pain did not change appreciably during the interval between onset and after examination

Starting pain (Table 18) occurring when the patient begins to move about, was noted in 56 (25 males and 31 females) of 91 patients Ten of those (3 males and 7 females) felt such pain bilaterally The group with such pain totaled 66 of 125 arthrotic hip joints The remaining 35 patients denied such pain so that 59 arthrotic hips had no starting pain

Pain when walking (Table 18) was reported as severe by 19 patients (7 males and 12 females) in all together 23 hips 5 of these patients had slight pain in the other hip Forty seven patients (20 males and 27 females) had slight pain in all together 59 hips The remaining 30 patients (43 hips) had no pain when walking

Pain during rest (Table 18) Spontaneous hip pain was reported by 5 patients (4 males and 1 female) in 8 hips Pain after exercise (disappeared during rest) was reported by 18 patients (5 males and 13 females) in 21 hip Sixty eight patients (96 hips) had no pain during rest

Table 18 *Incidence of pain in 91 patients with 125 arthrotic hips*

	Number of patients		Number of hips	
Starting pain	56		66	
Pain when walking	66		82	
Slight		47		59
Severe		19		23
Resting pain	23		29	
After walking disappears during rest		18		21
Spontaneous		5		8

Severity of pain at time of the after examination as indicated by index was not related to sex or to the etiology of the disease. Seventy five per cent had a pain index of 2 or better with 35 painless hips out of 125 examined (Fig 5, Fig 15, 23). Two thirds of the hips had become less painful in 1962 compared with 1950—1954 (Table 19).

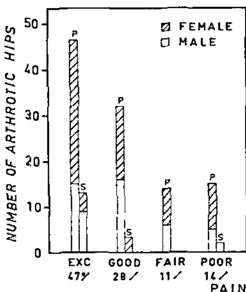


Fig 5
Number of arthrotic hips classified according to pain, patients' sex and etiology of the disease
P Primary coxarthrosis
S Secondary coxarthrosis

Table 19 *Severity of pain 1950—1954 compared with that at after examination in 119 arthrotic hips*

	Male	Female	Total
More severe	10	10	20
Unchanged	3	11	14
Less severe	28	42	70
Always painless	11	4	15
Total	52	67	119

b) *Physical Examination*

An objective clinical evaluation of coxarthrosis was obtained by measurement of the range of motion, leg length and circumference of the thigh, by the Trendelenburg test and body weight.

i *Range of Motion*

The range of motion was recorded in 1962 in 124 hips In one (3500) patient examined at home the range could not be assessed accurately The findings are summarised in Fig 6 The average range of motion in the different planes was flexion 60° (normal 110°) abduction plus adduction 20° (normal 45°) and total rotation 10° (normal 50°) Normal values are taken from SAARIO (1961)

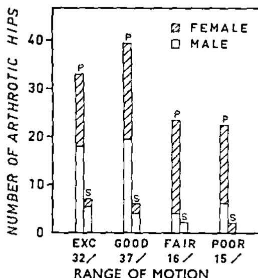


Fig 6
Number of arthrotic hips classified according to range of motion patients sex and etiology of the disease
P Primary coxarthrosis
S Secondary coxarthrosis

The mean range of motion in various planes was generally greater in secondary than in primary coxarthrosis but significantly** greater only for internal rotation The index of range of motion was higher* for males (42 4 $\pm$ 3 4) than for females (32 4 $\pm$ 2 9)

Flexion contracture was noted in 73 per cent of cases, external rotation contracture in 27 per cent adduction contracture in 22 per cent abduction contracture in 0 8 per cent (Fig 24)

ii *Relation of Contracture to Pain*

Previous Studies A correlation between contracture and severity of pain has often been stated in the literature but data for this conclusion are

lacking KUHNS (1942) stated that patients with coxarthrosis and contracture had more severe pain than those without contracture O'MALLEY (1959, 1962) suggested that contracture and severity of pain were related

Present Study Contractures in different planes were classified according to the deviation of the extended leg from normal

Group	Angle (Degrees)
0 =	0
1 =	1—15
2 =	16—30
3 =	31—45
4 =	46—60

Data about severity of pain and degree of contracture in 3 planes — flexion adduction and external rotation were available for 123 hips (Table 20)

A correlation was found between severity of pain and degree of contracture in the various planes The correlation was strongest for flexion contracture (Table 21) The number of painless hips decreased successively and severity of pain increased progressively (apart from flexion contracture group 3 which was noted in only 11 hips) The regression line for severity of pain on flexion contracture was obtained from the following equation

$$P = 0.61 + 0.76\,F$$

(P = severity of pain F = Flexion contracture group)

The severity of pain increased by 0.76 unit per group The correlation coefficient found between pain and flexion contracture was 0.51

The relationship between severity of pain and of contracture in adduction and external rotation respectively was not so close and was probably due to correlation between flexion adduction and external rotation contractures This was apparent from data given in Table 22 The severity of pain increased with that of adduction and external rotation contracture but this was probably only due to the correlation between the different contractures Good agreement was found between the observed and expected severity of pain The expected severity of pain was calculated from the equation given above

iii *Leg Length*

Patients with secondary coxarthrosis or with primary coxarthrosis when leg length discrepancy may have been due to an injury *e g* fracture were excluded

Table 20 *Arthrotic hips classified according to severity of pain and contracture*

Pain	Contracture												
	Flexion[1]					Adduction[11]			Lateral rotation[1]				
	0	1	2	3	4	0	1	2	0	1	2	3	4
0	27	9	5	3	—	41	2	1	36	3	5	—	—
1	1	4	7	2	—	8	6	0	6	5	3	—	—
2	5	16	13	1	—	26	7	2	19	4	8	4	—
3	1	4	7	2	—	10	2	2	7	2	4	—	1
4	—	3	4	1	1	5	1	2	5	2	1	—	1
5	—	—	5	2	1	6	2	0	4	—	3	1	—
Total	34	36	41	11	2	96	20	7	77	16	24	5	2

[1] 1 patient excluded (3500)

[11] 2 patients excluded (3500 3571)

Table 21 *Arthrotic hips classified according to flexion contracture and mean severity of pain*

Flexion contracture	Number of arthrotic hips	Number of arthrotic hips always painless	Mean intensity of pain
0	33	2	0.4
1	35	9	1.6
2	41	5	2.3
3	11	3	2.2
4	3	0	3.7
Total	123	44	1.6

Table 22 *Arthrotic hips classified according to contracture observed and expected severity of pain*

Contracture	Number of arthrotic hips	Mean		
		Observed severity of pain	Flexion contracture	Expected severity of pain
Adduction				
0	96	1.5	1.2	1.5
1	20	2.0	2.0	2.1
2	7	2.6	1.9	2.0
External rotation				
0	77	1.4	1.0	1.4
1	16	1.7	1.7	1.9
2	24	2.1	2.0	2.2
3	5	2.6	1.[illegible]	1.5
4	1	3.3	1.0	2.2

Shortening > 1 cm of the affected limb (anterior superior iliac spine to medial malleolus) was noted in 18 cases (14 lateral 2 medial 2 mixed type) On comparison with the total material considered (61 lateral 28 medial 36 mixed type) shortening was found to be more common* in the lateral than in the medial or mixed type of coxarthrosis

iii *Thigh Atrophy*

Circumference of the thigh was measured 15 cm above the proximal end of the patella with the knee extended One case was excluded because of an above knee amputation In 4 cases the circumference was greater on the affected side due to below knee amputation thrombosis lymphoedema or fracture involving the knee joint The remaining 86 patients are summarised in Table 23

Table 23 *Arthrotic hips with or without associated thigh atrophy classified according to localisation of arthrosis*

Thigh atrophy	Male	Female	Total	Lateral	Medial	Mixed
None	11	15	26	2	9	8
1 cm	6	15	21	10	5	6
2 cm	9	9	18	11	2	5
3 cm	4	8	12	9	1	2
4 cm	5	4	9	7	0	2
Total	35	51	86	46	17	23

Disease was bilateral in 11 of 26 patients with equal thigh circumference Atrophy was more common and more advanced* in the lateral than in the medial or mixed type of coxarthrosis

iiii *Trendelenburg Test*

The Trendelenburg test was positive in 28 hips (10 males and 18 females) negative in 79 (39 males and 40 females) and questionable in the remaining 16 hips (4 males and 12 females) One bed ridden patient (1344) could not be tested The Trendelenburg test was more frequently*** positive in lateral than in medial or mixed type of coxarthrosis

iiiii *Body Weight*

Previous Studies Obesity has been considered as an etiological factor in coxarthrosis (RASMUSSEN 1951 STECHER 1961) as a precipitating factor (WIBERG 1939 b) and as a factor accentuating pain (HOLLANDER 1957) DENHAM (1959) showed that reduction of body weight by one pound reduced the load on the hip joint by 3 pounds The importance of weight reduction in the treatment of this disease has been stressed by MCFARLAND (1954) LOCKIE and TALBOTT (1957) and many others

Present Study Ideal body weight in kilograms was defined as (height in cm minus 100) $\pm$ 10 per cent over weight > ideal body weight > under weight (WERNER and BERFENSTAM 1960)

The heights and weights of 115 patients at time of examination in 1962 are shown in Table 24 Fifty four (47 per cent) were over weight while only 13 (11 per cent) were under weight

Table 24 *Coxarthrotic patients classified according to weight[1] and surgery*

	Male				Female				Total			
	Under weight	Ideal weight	Over weight	Total	Under weight	Ideal weight	Over weight	Total	Under weight	Ideal weight	Over weight	Total
Non operated												
Secondary	—	5	3	8	1	4	—	5	1	9	3	13
Primary	4	14	12	30	5	15	26	46	9	29	38	76
Total	4	19	15	38	6	19	26	51	10	38	41	89
Operated												
Secondary	—	1	—	1	—	1	1	2	—	2	1	3
Primary	2	5	5	12	1	3	7	11	3	8	12	23
Total	2	6	5	13	1	4	8	13	3	10	13	26
Total												
Secondary	—	6	3	9	1	5	1	7	1	11	4	16
Primary	6	19	17	42	6	18	33	57	12	37	50	99
Total	6	25	20	51	7	23	34	64	13	48	54	115

[1] Height and weight not given for two patients (3500 1344)

Table 25. *Severity of pain in non-operated and operated patients grouped according to body weight*

	Severity of pain	
	Mean	S.E.M.
Non-operated		
Under weight	1.2	± 0.19
Over weight	2.0	± 0.15
Operated		
Under weight	1.3	± 1.25
Over weight	1.7	± 0.33
Total		
Under weight	1.2	± 0.32
Over weight	1.9	± 0.11

Table 25 shows that the mean severity of pain was higher for over weight than under weight patients. This difference was significant* only in the unoperated group.

Comments. The results showed that patients with coxarthrosis were more often over weight than under weight, but *probably not more often than* in a control material (WERNER and BERFENSTAM 1960). Over weight patients had more severe pain than under weight patients.

c) *Restriction of Function*

An assessment was made according to Table 8. Two thirds of the patients found it difficult or impossible to put on shoes and socks (Table 26).

Table 26. *Ability to put on own shoe and sock*

	Number of coxarthrotic pat.			Number of arthrotic hip		
	Male	Female	Total	Male	Female	Total
Easily	15	13	28	22	16	38
With difficulty	14	14	28	19	17	36
Not able	9	26	35	12	39	51
Total	38	53	91	53	72	125

Half of the patients could walk unaided and one third used one stick (Table 27). Two thirds could walk more than 400 meter without pain

Table 27 *Walking ability*

Walking outside	Male	Fem	Total	Distance walked without pain	Male	Fem	Total	Stair climbing	Male	Fem	Total
Unaided	20	25	45	> 1500 m	19	19	38	Unaided	15	12	27
Requires 1 stick	13	0	33	400—1500 m	5	13	18	Require stick or hand rail	13	1	38
Requires 2 sticks	3	5	8	100—400 m	3	3	6				
Requires 2 trestle	1	—	1	1 —100 m	10	15	25	Requires stick and hand rail	9	14	23
Not at all	1	2	3	Not at all	1	3	4	Unable	1	2	3
Completely bed ridden	—	1	1								
Total	38	53	91	Total	38	53	91	Total	38	43	91

Table 25 *Severity of pain in non-operated and operated patients grouped according to body weight*

	Severity of pain	
	Mean	S E M
Non-operated		
Under weight	1 2	± 0 19
Over weight	2 0	± 0 15
Operated		
Under weight	1 3	± 1 25
Over weight	1 7	± 0 33
Total		
Under weight	1 2	± 0 32
Over weight	1 9	± 0 11

Table 25 shows that the mean severity of pain was higher for over weight than under weight patients This difference was significant* only in the unoperated group

Comments The results showed that patients with coxarthrosis were more often over weight than under weight but probably not more often than in a control material (WERNER and BERFENSTAM 1960) Over weight patients had more severe pain than under weight patients

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With difficulty	14	14	28	19	17	36
Not able	9	26	35	12	39	51
Total	38	53	91	53	72	125

Half of the patients could walk unaided and one third used one stick (Table 27) Two thirds could walk more than 400 meters without pain

One third could not climb stairs unaided (Table 27) Two fifths of the patients reported difficulty in using a toilet and one third were unable to take a bath without a istance (Table 28)

Twelve patients had received a di ability pension

The patients work and activitie before the on et of the disea e and at the time of the after examination are summarized in Fig 7 Working ability decreased ignificantly *** and more for females (t = 8 8) than for males (t = 4 3) At the time of after examination no difference was found between the sexes

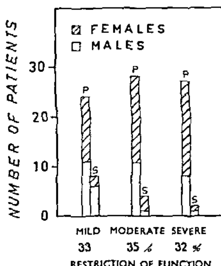


Fig 8
imber of coxarthrotic patient classified according to restriction of function sex and etiology of the di ea e

mments

In one third of the patients the restriction of function was severe ig 8) which means that the patient 'needs the a istance of other ople for his day to day existence (SHEPHERD 1954 a) The mean index restriction of function was 9 6 ± 0 60 and did not differ significantly th ex or etiology (primary versus econdary coxarthro is)

3 Radiographic Evaluation (1950—1954 and 1962)

a) *Previous Studies*

IARRISON et al (1953) showed experimentally that the structural nges of coxarthrosis regressed when pressure on joint surfaces iced Regression of changes seen radiographically in

ing operation upon the opposite hip has been noted by POUYANNE and HONTON (1960) Similar regression of radiographic changes in the operated hip following osteotomy and operations upon muscles has been reported by OSBORNE and FAHRNI (1950), WARDLE (1955), VOSS (1956) ADAM and SPENCE (1958) MCSWEENEY (1958), ROBINS and PIGGOT (1960), and PAUWELS (1961) ARDEN (1957) and HIRSCH (1960) pointed out that such radiographic changes may be due to difference in projection

b) *Present Study*

1 *Severity of Radiographic Changes*

In 1950—1954 and/or 1962 coxarthrosis was diagnosed radiographically in 125 hips Of these 121 were radiographed again in 1962 Four patients with unilateral disease in 1950—1954 would not consent to radiographic examination in 1962

The mean radiographic index was 4 8 ± 0 13 in 1950—1954 and 6 2 ± ± 0 13 in 1962 Neither in 1950—1954 nor in 1962 did the mean value differ significantly with sex or etiology (primary versus secondary coxarthrosis)

According to the system employed (Table 29) the radiographic changes progressed independent of sex in both primary and secondary coxarthrosis Primary coxarthrosis progressed radiographically more* than secondary (1 7 ± 0 13 versus 0 7 ± 0 13)

Table 29 *Radiographic progress—regression classified according to table 10*

	−3	−2	−1	0	+1	+2	+3	+4	+5	>+5	Total
Secondary											
Male	—	—	1	4	3	3	—	—	—	—	11
Female	—	—	—	3	3	—	—	—	—	—	6
Total	—	—	1	7	6	3	—	—	—	—	17
Primary											
Male	1	—	2	14	8	9	1	3	2	2	42
Female	—	1	3	13	12	11	7	7	6	2	62
Total	1	1	5	27	20	20	8	10	8	4	104
Total											
Male	1	—	3	18	11	12	1	3	2	2	53
Female	—	1	3	16	15	11	7	7	6	2	68
Total	1	1	6	34	26	23	8	10	8	4	121

One third of the entire material however showed *no progression* and in eight (4649 0053 0165 0320 0364 1259 2052 4414) hip *regression* was observed (Table 29 Fig 14 17 18 22) Of these patients 6 felt better one unchanged and one reported more severe pain

ii *Localisation of Radiographic Changes*

In 1950—1954 33 per cent were lateral 22 per cent medial and 45 per cent mixed types In 1962 48 per cent were lateral, 20 per cent medial and 32 per cent mixed There was no difference in sex distribution within these groups

The change in the radiographic localisation was because 22 mixed cases had become lateral (4 male and 18 female) and 4 medial (1 male and 3 female) and because 20 lateral (12 male and 8 female) and 21 medial (12 male and 9 female) were lost because the patients had died Three (2700 3118 3255) patients had lateral changes in one hip and medial changes in the other

Acetabular protrusion was noted in 5 4 per cent (2 males and 7 females) of 168 patients in the 1950—1954 group and in 5 3 per cent (6 females) of the 113 patients after examined in 1962 (Table 16)

iii *Signs and Symptoms in Relation to Radiographic Localisation* (Table 30)

There was no difference between the types with regard to age at onset sex or proportion of primary versus secondary coxarthrosis

The mean duration of pain was higher** in the lateral than in the medial or mixed type

The mean severity of pain index was higher*** in the lateral than in the medial or mixed type

The mean range of motion index was lower*** in the lateral than in the medial type and lower** in the medial than in the mixed type

The mean index for restriction of function was higher* in the lateral than in the medial type and higher*** in the medial than in the mixed type

The mean radiographic index in 1950—1954 was higher** in the lateral than in the medial or mixed type

The progression of radiographic changes judged according to Table 10 was greater* in the lateral than in the medial or mixed type

Table 30 *Coxarthrotic patients (P) and arthrotic hips (H) classified according to radiographic localisation age sex etiology severity of pain range of motion restriction of function radiographic severity and progression*

Radiographic localisation	Age at onset (H)		Duration (H)		Sex (H)		
	Mean	S E M	Mean	S E M	Male	Female	Total
Lateral	52 2	± 1 62	19 2	± 1 47	21	40	61
Medial	52 8	± 1 90	13 2	± 1 23	11	17	28
Mixed	51 5	± 2 77	13 7	± 3 14	21	15	36
Total					53	72	125

Radiographic localisation	Etiology (H)			Severity of pain (H)		Range of motion (H)	
	Secondary	Primary	Total	Mean	S E M	Mean	S E M
Lateral	7	54	61	2 1	± 0 11	23 3	± 2 12
Medial	3	25	28	1 1	± 0 24	39 1	± 4 70
Mixed	8	28	36	1 2	± 0 21	57 0	± 3 93
Total	18	107	125				

Radiographic localisation	Restriction of function (P)		Radiographic severity 1950—1954 (H)		Radiographic progression (H)	
	Mean	S E M	Mean	S E M	Mean	S E M
Lateral	12 1	± 0 68	5 7	± 0 28	2 0	± 0 25
Medial	8 6	± 1 36	4 0	± 0 19	1 1	± 0 28
Mixed	3 1	± 0 15	3 7	± 0 28	1 1	± 0 16

4 Bilateral Cases

Thirty four patients had bilateral coxarthrosis

a) *Pain*

In 13 patients one of the hips had always been painless Of the remaining 21 with bilateral pain 4 reported that pain had commenced on both sides at the same time In the 17 patients where pain had started at different time 9 had the same severity of pain on both sides 5 had less pain in the hip in which it had started first and 3 in the hip in which it had started later

The mean value found for severity of pain was 1 7 $\pm$ 0 14 This value did not differ significantly from that found for unilateral coxarthrosis The mean value for the more painful side was 2 4 $\pm$ 0 25 again t 1 1 $\pm$ 0 24 for the other side The difference was significant***

b) *Range of Motion*

Of the 17 patients in which hip pain had started at different times 5 had the same range of motion on both sides 9 had less on the fir t affected side and 3 on the other side

The mean range of motion was 34 9 $\pm$ 3 27 This value did not differ significantly from that found for unilateral coxarthro is The mean value for the hips affected most was 24 6 $\pm$ 4 03 and for tho e affected less 45 3 $\pm$ 4 52 The difference was significant***

c) *Restriction of Function*

The mean value (11 7 $\pm$ 1 06) was higher** than that found for unilateral coxarthrosis (8 4 $\pm$ 0 67)

d) *Severity of Radiographic Changes*

The mean index in 1962 (6 2 $\pm$ 0 26) did not differ significantly from that found for unilateral coxarthrosis

5 Operated Cases

Twenty eight patients of Series C had undergone operation for their coxarthrosis Two of these died before 1962 The surviving 26 patients (28 hips) were after examined in 1962 Coxarthrosis was primary in 23 patients (12 males and 11 females) and econdary in 3 (1 male and 2 females)

a) *Operative Methods*

The methods employed were varied and seven hips had been re operated once or more (Table 34)

The mean interval between the first operation and the after examination in 1962 was 6 8 $\pm$ 0 69 years

b) *Pain*

Pain was evaluated in the 28 operated hips examined in 1962 Fourteen patients (7 males and 7 females) or 15 hips had starting pain Pain when walking was classed as evere in 8 patients (3 males and 5 females) 9 hips and as slight in 10 patients (7 males and 3 females), 11 hips Three

(1 male and 2 females) or 3 hips had pain appearing spontaneously during rest Pain after exercise (disappeared during rest) was reported by 4 patients (3 males and 1 female) 5 hips

Six patients (3 males and 3 females) or 6 hips, were free from pain One (0680) patient had an 11 year old Smith Petersen cup with good range of motion and moderate restriction of function, two (2495, 4464) patients had 11 and 8 year old arthrodesis with moderate restriction of function two (1837 4540) patients had 6 and 3 years previously undergone a Voss operation with excellent respectively good range of motion and moderate restriction of function One (2495) patient had 6 years previously had a broken Judet prosthesis removed At the after examination he had an excellent range of motion and a mild restriction of function

Six patients with bilateral coxarthrosis had been operated upon on one side only On the non operated side 3 hips had never been painful, and 3 hips had less pain following the operation

c) *Restriction of Function*

None of the patients could manage moderate or heavy physical work nine (4 males and 5 females) had light work ten (6 males and 4 females) slight work and seven (3 males and 4 females) could not manage any work at all Seven of the patients operated upon had after operation received a disability pension

The Trendelenburg test was positive in 21 hips (12 male and 9 female) questionable in 4 hips (3 male and 1 female) and negative in 3 hips (all female) In the negative group the three operations had been cup arthro plasty arthrodesis and division of the obturator nerve with synovectomy

d) *Severity of Radiographic Changes*

Regression was noted in two (4582 4540) patients both with congenital dislocation One had had an osteotomy and the other a Voss operation In the latter patient who had bilateral disease the structural changes regressed also in the non operated hip

6 Comparison between Patients Operated upon Offered but Refused Operation and Not Offered Operation

The relatively good results regarding pain range of motion and restriction of function in the conservatively treated cases were remarkable It might be objected that this was due to selection of the patients operated upon i e that those patients operated upon were presumably those in whom the disease was more advanced In order to check this possibility the

Table 31 *Coxarthrotic patients (I) and arthrotic hips (II) classified according to surgery, age, sex, etiology, severity of pain, range of motion, restriction of function and radiographic localisation and severity*

	Age (P)		Sex (P)		
	Mean	S E M	Male	Female	Total
I Operated	70 5	±1 95	13	13	26
II Refused operation	6[illegible] 7	±1 44	11	24	35
III Operation not offered	69 9	±1 41	27	29	56
Total			51	66	117

	Etiology (P)			Severity of pain (H)	
	Secondary	Primary	Total	Mean	S E M
I Operated	3	23	26	1 5	±0 22
II Refused operation	5	30	35	1 7	±0 13
III Operation not offered	9	47	6	1 6	±0 13
Total	17	100	117		

	Severity of pain 1950—1954 compared with that at after examination (H)				
	More severe	Unchanged	Less severe	Always painless	Total
I Operated	4(12%)	6(17%)	21(62%)	3(8 8%)	34
II Refused operation III Operation not offered	20(17%)	14(12%)	70(59%)	15(12%)	119

	Range of motion (H)		Restriction of function (P)		Radiographic localisation 1950—1954 (H)			
	Mean	S E M	Mean	S E M	Lateral	Medial	Mixed	Total
I Operated	38 8	±3 98	14 0	±1 18	14	2	18	34
II Refused operation	33 7	±3 48	9 0	±0 73	17	12	19	48
III Operation not offered	39 0	±3 04	10 8	±0 79	24	14	33	71
Total					55	28	70	153

	Radiographic severity 1950—1954 (H)	
	Mean	S E M
I Operated	5 3	± 0 39
II Refused operation	4 7	± 0 25
III Operation not offered	5 1	± 0.19

material was divided into three groups (I) operated (II) refused operation (III) operation not offered (Table 31) In the operated group all values were noted *for all coxarthrotic hips and not only for those operated* upon No significant difference was found regarding age etiology pain, range of motion or radiographic severity Females tended to refuse operation more often than males The difference was however not significant Restriction of function was more severe for the group that accepted operation than for the group that refused*** or that which was not offered operation* Among those operated upon medial coxarthrosis was less common* than statistically expected Of the patients offered operation the observed number with medial coxarthrosis who refused operation was higher* than the expected

Comments

The fact that the observed number of patients with medial coxarthrosis who refused operation was higher than statistically expected, and that the observed number of medial coxarthrosis was lower in the *surgical series than expected suggests that medial coxarthrosis is clinically* less severe than lateral The fact that no further differences between the three groups were primarily demonstrable suggests that the indication for operation was uncertain or questionable Operation appeared to restrict function

7 Summary

Series C (168 patients) comprised all cases of primary and secondary coxarthrosis diagnosed in the Orthopaedic Clinic Malmo in the five year period 1950–1954 While the sexes were equally common at the time of diagnosis females predominated slightly at the time of after examination in 1962 because of the relatively higher mortality of males in older age groups Secondary coxarthrosis accounting for 11 per cent of the cases at diagnosis rose to 15 per cent in 1962 because of the higher mean age and hence higher mortality of the primary group

The occurrence of bilateral disease in one third of the patients was independent of sex and strongly suggested that coxarthrosis is a disease *sui generis*

To study the natural history of coxarthrosis pain range of motion restriction of function and radiographic appearance were evaluated in 1962 and compared whenever feasible with the status of the patient at the time of diagnosis In this way some information was obtained regarding the course of untreated coxarthrosis A small operated group was evaluated in the same way

Pain was regarded as the chief symptom of coxarthrosis and it came as an indication of the onset of joint disease The mean age at onset of primary coxarthrosis was 55 years and of secondary coxarthrosis 41 years Pain was felt on the first side in bilateral cases at the same age as in unilateral cases The age at onset was independent of sex and localisation of radiographic changes

Localisation of pain was unchanged from the time of onset to the after examination About one half of the patients reported pain in the region of the greater trochanter one quarter in the groin and one quarter in the region of the knee

Starting pain was noted in half of the cases, pain when walking in two thirds and resting pain in one quarter Spontaneous pain occurred in 5 per cent of the cases At the time of after examination two thirds of the patients felt that their pain had decreased

Restricted range of motion was invariably noted and thus more common than pain The degree of contracture particularly flexion contracture bore a direct relation to severity of pain

Leg length discrepancy and thigh atrophy were more marked in the lateral type of coxarthrosis Over weight was not more common among patients with coxarthrosis than among the population in general Hip pain was more common among over weight than among under weight patients with coxarthrosis

One third of the patients required help in their daily life The restriction of function was not related to sex or to etiology of the disease

Radiographic changes usually progressed but regressed in 8 cases Progression was more marked in primary coxarthrosis Improvement of radiographic changes was not necessarily accompanied by improvement in the clinical status From the time of diagnosis until the after examination there was a tendency for the lateral type of coxarthrosis to increase (from one third to one half of cases) at the expense of the mixed cases

A comparison of lateral type of coxarthrosis with medial type showed that on the whole the lateral type had a higher mean age greater severity of pain greater restriction of joint motion and function and a higher rate of progression than the medial type

IV GENERAL DISCUSSION

A COMPARISON BETWEEN THE PRESENT NON-OPERATED SERIES AND PUBLISHED OPERATED SERIES

To what extent does the selection of patients for operation effect the composition of operated and non-operated series? Whether a given patient is operated upon depends on the attitude of the surgeon and of the patient. Indications for operation vary widely from surgeon to surgeon, from one department to another and from year to year (WIBERG 1958). For a number of reasons the effect of the selection by the surgeon cannot be eliminated by operating upon alternate patients.

Operation introduces two factors difficult to evaluate, namely the psychological effect of the operation and bedrest after the operation. It cannot be denied that patients and surgeons have a strong belief in the value of surgery. The progressive recovery after operation (bed rest, trestles, crutches, sticks) gives the patient a feeling of improvement even in the absence of any true improvement compared with his condition before operation. The postoperative regimen involves weeks and months of bed rest. The question that then arises is how much any postoperative improvement is due to the operation and how much to rest. It is difficult to prescribe such a long period of strict rest and immobilisation without operation. Is operation only a means of forcing the patient to accept an extremely strict conservative regimen?

1 Difficulties in Comparison of Clinical Materials

The value of any comparison between operated and non-operated series is limited by the fact that two strictly comparable series are not available. With this limitation in mind the present non-operated material was compared *with surgical series described in the literature*. *Strict comparison* is not possible because the criteria used for the diagnosis, clinical and radiographic evaluation of the published series were not uniform. Published operated series and the present non-operated series are summarized in tabular form (Table 32). The operated series are classified according to the surgical method used. In the osteotomy material the authors did not always distinguish between displacement, valgus or varus osteotomy.

Objections that may be raised against the materials are:

a) The Present Non-operated Series

Twenty-eight (17 per cent) of the 168 original patients had been operated upon. In spite of the fact that the localisation of the radiographic

changes was the only difference found between those who were subjected to operation those who refused operation and those who were not offered operation it is tempting to assume that the patients with the most severe pain were operated upon

In the present material 13 per cent of the arthrotic hips had always been painless

b) *Operated Series*

The results have not been judged by uniform criteria

The results are based partly on afterexamination and partly on the personal opinions of the authors

Some authors do not state the size of the original material compared with that presented and others give only approximate figure Unless all surviving patients are afterexamined and accounted for any conclusions drawn may be unreliable SHEPHERD (1960) showed that the patients in whom operation had given least relief refused to consent to an after examination

The interval between the operation and the after examination varied widely within and between series It is not possible to say to what extent this affected the results described

2 Pain

Only arthrodesis guarantees freedom from pain In none of the series was this always achieved Partial or complete freedom from pain was however reported after all types of therapy conservative and surgical whether technically successful or unsuccessful operations (prosthese that had been removed attempted arthrodesis without bony union) An analysis of the data in published series (not including arthrodesis) showed that 56 per cent were painless while 12 per cent had severe pain In the non operated series the corresponding figures were 35 per cent and 14 per cent

It appears that operation provides complete freedom from pain more frequently than conservative treatment while the incidence of severe pain is the same for both methods

Decrease in pain was somewhat more often reported in the surgical series (87 per cent) than in the present unoperated series (71 per cent)

3 Range of Motion

While surgical methods aim either at increasing or preserving range of motion of the hip or at arthrodesis such results cannot be consistently obtained

Only resection of the femoral head and neck will give permanent improvement of range of motion. Arthroplasty such as Smith-Petersen cup and Judet prosthesis gives early but not permanent improvement of range of motion (SHEPHERD 1954 b). Osteotomy is usually followed by unchanged or reduced range of motion (HIRSCH 1960, KING and DOOLEY 1962). CAMPBELL and JACKSON (1956) reported 43 per cent and NICOLL and HOLDEN (1961) 34 per cent ankylosis following osteotomy. The incidence of ankylosis (15 per cent) in the present unoperated material was thus lower.

Operations to secure arthrodesis in the series on record resulted in bony union in somewhat more than half of the cases. If all attempts at arthrodesis of the hip joint were known it would probably reveal that 50 per cent of the operations did not result in bony union and that the operation and postoperative immobilization reduced the range of motion not only of the hip but also — and probably to an equal extent — of the knee.

4. Restriction of Function

Single cases have been described in which the patient could return to heavy work, but none of the publications state whether the average working capacity was improved. It is very probable that the restriction of function increased. MOVIN (1957) reported a positive Trendelenburg test in 70 per cent of an alloplastic series and STEIN and COSTEN (1962) twenty-three patients of 32 in a series treated with metal prosthesis. KERSSEMAKERS (1961) found that 63 *per cent of a series* treated with arthroplasty could not manage without a stick. The difficulties following successful arthrodesis (using toilet, climbing stairs, putting on shoes and socks) as well as the increased frequency of knee stiffness and back pain are well known.

In series on record the results have been judged as poor in 34 per cent of a series treated with a Smith-Petersen cup (SHEPHERD 1960), in 11 *(34 per cent) of a series treated with a metal prosthesis (STEIN and COSTEN* 1962), in 6 per cent treated with arthrodesis (MCKEE 1957), in 38 per cent (ADAM and SPENCE 1958), 17 per cent (ROBINS and PIGGOT 1960) and 37 per cent (SHEPHERD 1960) in series treated with osteotomy. No figures are available for the results of valgus osteotomy or muscle release operations.

In the present non-operated material Trendelenburg test was positive or questionable in 36 per cent, which means less often than in operated series. The relative number of patients who could not walk unaided (49 per cent) was lower than in the operated series. The incidence (32 per cent) of poor results was roughly the same as in operated series. Only patients with arthrodesis showed results *better than those in the present non-operated series*.

5 Conclusion

The comparison showed that

Complete relief of pain can only be expected with certainty after successful arthrodesis but complete or partial relief of pain is probably obtained more often after surgical than after conservative treatment

Range of motion is unchanged or decreased after operation

Restriction of function is unchanged or increased after operation

The investigation does not warrant any conclusion whether coxarthrosis should be treated surgically and if so which cases and by which methods Such a conclusion would require that all patients those treated surgically and those treated conservatively be continually examined with a uniform system at various hospital Data could then be pooled to provide comparable series large enough to permit conclusive comparison

V GENERAL SUMMARY

A RADIOGRAPHIC DIAGNOSIS AND DEFINITION OF COXARTHROSIS

In order to define radiographic criteria, the radiographs of all patients diagnosed as coxarthrosis during the year 1951 were reviewed Structural or joint space changes, evident radiographically in one out of every 7 cases in 1951, persisted at the time of review in 1962 In the remaining cases the diagnosis had been based upon the presence of osteophytic changes alone In only one of 86 such cases reviewed in 1962 had structural or joint space changes developed

Osteophytes had no clinical significance and did not progress to coxarthrosis Osteophytes appear to be a part of normal age changes in the hip joint

The radiographic diagnosis of coxarthrosis must be based upon the demonstration of structural or joint space changes

B INCIDENCE OF PRIMARY COXARTHROSIS

To estimate the incidence of primary coxarthrosis the age and sex specific incidence was determined in the series of cases diagnosed in Malmo during the five year period *1950—1954* *Morbidity* was equal in both sexes Mortality was the same as in the general population The slightly higher number of female cases in older age groups was related to the higher mortality of males at these ages

The incidence of new cases of primary coxarthrosis was about half that of fracture of proximal end of the femur The total number of cases in the population will increase as a result of the trend to aging of the population since this is a disease in which incidence increases markedly with age

C NATURAL HISTORY OF COXARTHROSIS

The natural history of coxarthrosis was studied by observing the course of the disease over a 10 year period in all patients with primary and secondary disease diagnosed during the five year period 1950—1954 (168 patients)

About one in 9 cases in this series was classed as secondary and the sexes were equally represented The occurrence of bilateral disease in one third of the patients strongly suggested that primary coxarthrosis is a disease sui generis

Four out of 10 patients died within 10 years of diagno is of the di ea e

To determine the progno i in this di order and to provide a tandard of compari on for operated ca es 91 non operated ca e were evaluated clinically and radiographically One in 8 of all arthrotic joints had always been painle At after examination one third were painle and one quarter had severe pain two thirds of the patients reported a decrea e of pain A correlation was noted between pain and degree of joint contracture Pain tended to be more severe in over weight patient

All cases had some restriction of range of motion which occurred mo t often with regard to internal rotation Two third of the cases had good or excellent range of motion

Re triction of function increa ed over the 10 year period Only a few patients could do heavy work One third required a i tance for their day to day existence

The radiographic changes were evaluated by comparing the radiographs with tho e taken at the time of after examination in 1962 In 7 per cent of ca e there was real or apparent regre ion of arthrotic changes

Lateral coxarthro is defined radiographically has a poor progno is radiographic changes progre ed more rapidly range of motion and function became more re tricted and pain was more evere than in the medial type

The over all late progno is is good for two third of non operated ca es

Attempts to compare the results in this non operated eries with tho e in published operated series indicate the need for a uniform sy tem of cla sification and examination

VI APPENDIX

A RADIOGRAPHIC REPRODUCTIONS

VI APPENDIX

A RADIOGRAPHIC REPRODUCTIONS

Fig 9 (1083)

Female aged 72 Radiographic examination in 1951 because of accident Hips always painless *1962* No pain Range of motion normal (72/72) Restriction of function mild (2)

Radiographic appearance

1951 Osteophytes on both poles Joint space normal Structure normal No double floor

1962 As in 1951

Interpretation Osteophytes unchanged No structural or joint space changes developed

Fig 10 (1381)

Male aged 74 Radiographic examination in 1951 because of minor trauma Hips always painless

1962 No pain Range of motion normal (79/79) Restriction of function mild (2)

Radiographic appearance

1951 Osteophytes on both poles Joint space normal Structure normal No double floor

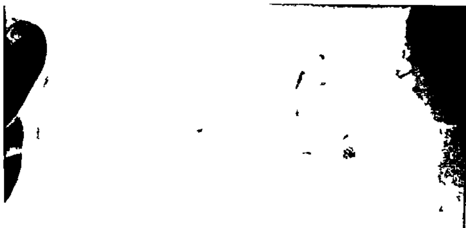
1962 As in 1951

Interpretation Osteophytes unchanged No structural or joint space changes developed

Fig 9

1951 1962

Fig 10



1951 1962

Fig 11 (1578)

Male aged 58 Radiographic examination in 1951 because of back weakness Hips always painless *1962* No pain Range of motion normal (83/83) Restriction of function mild (2)

Radiographic appearance

1951 Osteophytes on both poles Joint space normal Structure normal No double floor

1962 As in 1951

Interpretation Osteophytes unchanged No structural or joint space changes developed

Fig 12 (1740)

Male aged 57 Radiographic examination in 1951 because of lumbar pain and sciatica Hips always painless *1962* No pain Range of motion normal (82/82) Restriction of function mild (2)

Radiographic appearance

1951 Osteophytes on both poles Joint space normal Structure normal No double floor

1962 As in 1951

Interpretation Osteophytes unchanged No structural or joint space changes developed

Fig 11

1951 1962

Fig 12

1951 1962

Fig 13 (4479)

Male aged 68 Bilateral congenital di location Di ability pension during shipping depression afterwards returned to u ual occupation (stower) Hip always painless *1962* No pain. Range of motion excellent (66/89) on both side Restriction of function mild (6)

Radiographic appearance

1954 Right Locali ation mixed Bulky o teophytes on both poles Joint space less than half normal width Structural changes in femoral head and acetabulum (gro sly destroyed) Double floor

Left Locali ation mixed Joint space normal" Structural changes in femoral head No double floor

1962 Right Localisation mixed Bulky o teophytes on both poles Joint space less than *half normal width Structural changes in femoral head and acetabulum (grossly de troyed)* Double floor

Left Locali ation mixed. Joint space "normal Structural changes in femoral head. No double floor

Interpretation Largely unchanged radiographic appearance

Fig 13 1954





1962

Fig 13 (44/9)

Male aged 68 Bilateral congenital di location Di ability pension during shipping depression afterwards returned to u ual occupation (stower) Hips always painle s *1962* No pain Range of motion excellent (66/89) on both sides Restriction of function mild (6)

Radiographic appearance

1954 Right Localisation mixed Bulky osteophytes on both poles Joint space less than half normal width Structural changes in femoral head and acetabulum (grossly destroyed) Double floor

Left Localisation mixed Joint space normal" Structural changes in femoral head No double floor

1962 Right Localisation mixed Bulky osteophytes on l oth poles Joint space less than half normal width Structural changes in femoral head and acetabulum (gro sly destroyed) Double floor

Left Localisation mixed Joint space normal Structural changes in femoral head No double floor

Interpretation Largely unchanged radiographic appearance

Fig 14



1950 1962

Fig 15 (0168)

Female aged 75 Bilateral primary coxarthrosis Onset of bilateral pain at 57 years Refused operation Pain slowly but steadily decreased on both sides *1962* Both hips painless Range of motion good (17) on right side fair (23) on left Restriction of function mild (4)

Radiographic appearance

1950 Right Localisation lateral Osteophytes on both poles Joint space narrowed but more than half normal width Structural change in femoral head and acetabulum no double floor

Left Localisation lateral Osteophytes on both poles Joint space narrowed but more than half normal width Structural changes in femoral head and acetabulum Double floor

1962 Right Localisation lateral Bulky osteophytes on both poles Joint space less than half normal width Structural changes in femoral head and acetabulum Double floor

Left Localisation lateral Osteophytes on both poles Joint space narrowed but more than half normal width Structural changes in femoral head and acetabulum Double floor

Interpretation Right Slight but definite radiographic progress Left Largely unchanged

Fig 15

1950





1962

Fig. 16 (0174)

Female aged 68 Right sided primary coxarthrosis On set of pain at 55 years Arthrodesis offered but refused Pain slowly but steadily decreased *1962* Very slight starting pain no pain when walking no resting pain (1) Ankylosis Restriction of function moderate (8) managed her housework alone (7 members of family)

Radiographic appearance

1950 Localisation mixed Osteophytes on both poles Joint space narrowed but more than half normal width Structural changes in femoral head No double floor

1962 Localisation lateral Osteophytes on both poles Joint space effaced over more than half femoral contour Structural changes in femoral head and acetabulum (grossly destroyed) Double floor questionable

Interpretation Marked radiographic progress

Fig. 17 (0320)

Female aged 71 Bilateral primary coxarthrosis On set of pain at 36 years on right side and at 41 on left Pain slowly but steadily decreased on right side unchanged on left *1967* Right Slight starting pain severe pain when walking no resting pain (3) Left Starting pain slight pain when walking no resting pain (2) Ankylosis on both side Restriction of function severe (15)

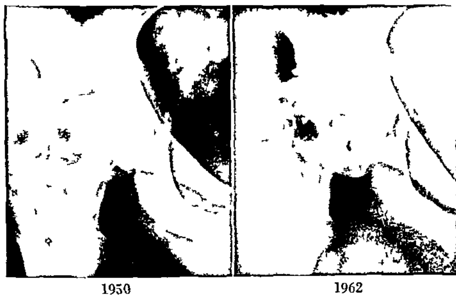
Radiographic appearance

1950 Left Localisation lateral Osteophytes on both poles Joint space effaced over more than half femoral contour Structural changes in femoral head and acetabulum (grossly destroyed) No double floor

1967 Left Localisation lateral Osteophytes on both poles Joint space less than half normal width Structural change in femoral head and acetabulum No double floor

Interpretation Radiographic regression of structural and joint space change

Fig 16



1950 1962

Fig 17

1950 1962

Fig 18 (0364)

Female aged 87 Right sided primary coxarthrosis Onset of pain at 73 years Pain slowly but steadily decreased *1962* Hip painle Range of motion excellent (61) Restriction of function moderate (12) (due partly to blindne)

Radiographic appearance

1950 Localisation lateral Bulky osteophytes on both poles Joint space effaced over more than half femoral contour Structural changes in femoral head and acetabulum Double floor

1962 Localisation lateral Bulky osteophytes on both poles Joint space less than half normal width Structural changes in femoral head and acetabulum Double floor

Interpretation Regression of joint space changes (effect of projection?)

Fig 19 (0608)

Male aged 81 Left sided primary coxarthrosis Onset of pain at 61 years Pain slowly but steadily decreased *1962* Very slight starting pain very slight pain when walking no resting pain (2) Range of motion good (41) Restriction of function moderate (8)

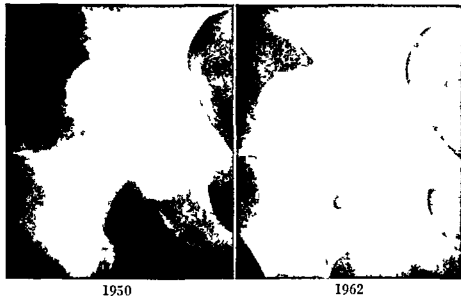
Radiographic appearance

1950 Localisation lateral Osteophyte on one pole Joint space narrowed but more than half normal width Structural change in femoral head No double floor

1962 Localisation lateral Osteophytes on both poles Joint space effaced over more than half femoral contour Structural changes in femoral head and acetabulum (grossly destroyed) Double floor

Interpretation Marked radiographic progre

Fig 18



1950 1962

Fig 19

1950 1962

Fig ?0 (1315)

Female aged 70 Bilateral primary coxarthrosis On et of pain at 53 years in ri ht hip at 56 years in left Pain lowly but steadily decrea ed in right and increased in left hip *1962* Right hip No starting pain slight pain when walking no resting pain (1) Left hip Starting pain severe pain when walking resting pain after walking (4) Right hip Ran e of motion excellent (56) Left hip Ankylosis Restriction of function severe (16)

Radiographic appearance

1951 Right Locali ation mixed O teophytes on both poles Joint space le s than half normal width Structural changes in femoral head and acetabulum No double floor

Left Locali ation mixed No osteophyte Joint space normal Structure normal No double floor

1962 Right Locali ation mixed O teophytes on both poles Joint space le s than half normal width Structural changes in femoral head and acetabulum No double floor

Left Locali ation lateral O teophytes on both poles Joint space effaced over more than half femoral contour Structural changes in femoral head and acetabulum Double floor

Interpretation Right Largely unchanged radiographic appearance Left Development f coxarthro i Marked radiographic progre s

Fig 20 1951





1962

Fig 21 (1335)

Male aged 74 Bilateral primary coxarthro is Radiographic examination because of minor trauma Both hips always painle s *196.* No pain Range of motion excellent on both sides (63/63) Re triction of function mild (3)

Ra liographic appearance

1951 Right Locali ation medial Osteophytes on both poles Joint space narrowed l ut more than half normal v idth Structural change in femoral head No double floor

Left Localisation medial Osteophytes on l oth poles Joint sp ace narrov ed but more than half normal width Structural changes in femoral head No doul le floor

1962 Right Locali ation medial O teophytes on l oth pole Joint space le s than half normal width Structural changes in femoral head No doul le floor

Left Localisation medial O teophytes on both pole Joint space less than half normal width Structural changes in femoral head No doul le floor

Interpretation Slight l ut definite radiographic p rogre s on l oth si le

Fig 21 1951





1962

Fig 22 (1607)

Female aged 83 Right sided primary coxarthrosis On set of pain at 68 years Pain unchanged *1962* No starting pain slight pain when walking pain during rest after walking (2) Range of motion good (35) Restriction of function severe (15)

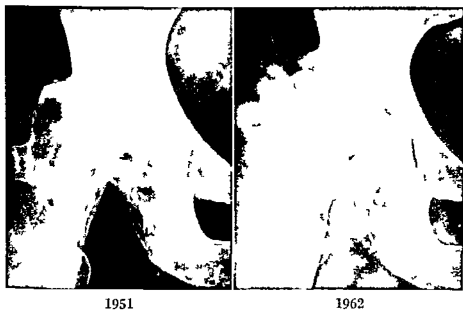
Radiographic appearance

1951 Localisation lateral Osteophytes on both pole Joint space less than half normal width Structural changes in femoral head and acetabulum Double floor

1962 Osteophytes on both poles Joint space narrowed but more than half normal width Structural changes in femoral head and acetabulum (grossly destroyed) Double floor

Interpretation Regression of joint space changes

Fig 22



1951 1962

Fig 23 (2524)

Female aged 84 Bilateral primary coxarthrosis On et of pain in right hip at 74 year left hip always painles Operation refused Pain lo\ ly but steadily decreased *1962* Both hips painles Range of motion fair (18) on right side good (42) on left Re triction of function mild (5)

Radiographic appearance

1952 Right Locali ation medial (acetabular protrusion) Osteophytes on both poles Joint space less than half normal width Structural changes in femoral head and acetal u lum No double floor

Left Locali ation medial (acetabular protrusion) Osteophyte on one pole joint space le s than half normal width Structural changes in femoral head and acetabulum No double floor

1962 Right Locali ation medial (acetal ular protru ion) O teophytes on both pole Joint space le s than half normal width Structural changes in femoral head and acetal ulum No doul le floor

Left Locali ation medial (acetabular protru ion) O teophyte on l oth poles Joint pace le s than half normal width Structural changes in femoral head and acetabulum No doul le floor

Interpretation Largely unchanged radiographic appearance on both side

Fig 23

1952





1962

Fig 21 (3571)

Male aged 73 Right sided primary coxarthrosis Onset of pain at 58 years Pain slowly but steadily increased *1962* Starting pain severe pain when walking pain during rest after walking (4) Range of motion fair (18) Abduction contracture Restriction of function severe (14)

Radiographic appearance

1953 Localisation medial Bulky osteophytes on both poles Joint space less than half normal width Structural changes in femoral head and acetabulum Double floor

1962 Localisation medial Bulky osteophytes on both poles Joint space less than half normal width. Structural changes in femoral head and acetabulum Double floor

Interpretation Marked progress of capital drop Radiographic appearance otherwise largely unchanged

Fig 24



1953 1962

B TABLES

Table 32 Survey of literature

Treatment	Number of cases		Interval between operation and after examination	Severity of pain	Range of motion	Restriction of function	Patient's own assessment
	Operated	After examined					
...al head resection Murray et al. (1963)	—	34	< 8 years	No pain 32 Required salicylates 2	—	—	
Arthroplasty a) Calf fascia or calf myocard Kerssemakers (1961)	125	119	$^{1}/_{2}$—5 years	No pain 74 Some pain 33 Severe pain 12	—	Walked without stick 14 Walked with one stick 57 Walked with two sticks 18	Very pleased 60 Reasonably content 45 Discontented 14
b) Smith Petersen cup Shepherd (1960)	—	176	> 4 years		*Conclusion* Including mobility Exc 9 % Good 27 % Fair 30 % Poor and failed 34 %		
c) Metal prostheses Stein and Co ten (1962)	48	32	1—9 years	No pain 7 Slight pain 8 Moderate pain 13 Severe pain 4	> 180° 2 175°—125° 10 120°— 75° 9 < 70° 10	Trendelburg test Pos 23 Neg 9	*Conclusion* Exc 3 Good 5 Satisfied 13 Poor 7 Failure 4

Treatment	Operated	After examine l	Tetwee i oj eration and fter examination	Se erity of pa i	Ra ge of motion	R tr ctio i f f i tion	l at nt ow i as e m nt
Arthrodesis							
Gade (1947)	27	°6		No pain 25	Bony ankylo is 23	—	
Gardiner (1953)	53	49		—	Bony ankylo is 3?	—	
Charnley (1955)	158	105		—	Bony ankylo is 18	—	
Wat on Jones and Robinson (1956)	—	120		—	Bony ankylo is 113	—	
Lindstrom (1957)	41	40		—	Bony ankylo is 38	—	
Debeyre (1958)	—	125		—	Bony ankylo is 52	—	
Kirkaldy Willis et al (1958)	—	37		—	Bony ankylo is 20	—	
McKee (1957)	—	50		No pain 31 Slight pain 12 Moderate pain 1 Unrelieved 1 Died 2	Bony ankylosis 47	I xe 20 Goo l 23 Fair [illegible] Faile l 1 Ba l 2	
Mortens and Jensen (1960)	43	39		No pain or relieved 33	Bony ankylo is [illegible]	—	
Piggot (1960)	98	91		No pain 81	Bony ankylo is 7[illegible]	—	
Axer (1961)	19	19		—	Bony ankylo is 1?	—	
Lipscomb and McCa lin (1961)	371	347		—	Bony ankylosis ? 1	—	

Treatment	Number of cases		Interval between operation and after examination	Severity of pain	Range of motion	Restriction of function	Patient's own assessment
	Operated	After examined					
Osteotomy a) Displacement and/or valgus osteotomy (Osborne and Fahrni) (19 0)	93	75	1—12 years	Relieved 61 Not relieved 14	—	—	
Campbell and Jackson (19)	—	16	1—20 years	No pain 2 Slight pain 1 Severe pain 6	No movement 6 Rock 9 5°—19° 11 20°—39° 9 > 40° 11	—	
Adam and Spence (1958)	87	57	9 m —18 years	No pain 26 Mild ache 20 Made concessions 7 Disabling pain 1 Crippling pain 3	*Conclusion* Including Mobility Exc. 14 % Good 29 % Fair 19 % Poor 38 %	Excluding Mobility Exc. 33 % Good 33 % Fair 14 % Poor 20 %	Satisfied 18 Dissatisfied 9
Hirsch (1960)	54	54	< 4 years	Complete relief 30 % Relieved 80 %	In no case better than before	Activity hardly increased. A great number forced to use a stick	

Treatment	Number of cases		Interval between operation and after examination	Severity of pain	Range of motion	Restoration of function	Patient's [illegible] assessment
	Operated	After examined					
Robins and Piggot (1960)	58	49	—		*Conclusion* Including mobility Exc. 23% Good 38% Fair 22% Poor 17%	Excluding mobility Exc. 40% Good 37% Fair 12% Poor 11%	
Nicoll and Holden (1961)	—	195	~ 1 year (18% > 5 years)	Abolished 101 Relieved 71 Same or more 23	Ankylosis 66	—	
Shepherd (1960)	—	134	> 4 years		*Conclusion* Including mobility Exc. 7% Good 28% Fair 28% Poor 37	Excluding mobility Exc. 2 Good 18 Fair 35% Poor 22%	
King and Dooley (196?)	—	45	?–?0 years	No pain	Stayed much the same as before op.		

Treatment	Number of cases		Interval between operation and after examination	Severity of pain	Range of motion	Restriction of function	Patient's own assessment
	Operated	After examined					
Ottolenghi and Frigerio (196[illegible])	—	103	1—17 years	No pain 80 Occasional pain 9 No relief [illegible]	Equal to or more than before op 75 Less than before op 28	No restriction of activity 75 Some restriction of activity 13 Definite restriction of activity 9 No increase 6	Satisfied 97 Dissatisfied 6
I) Varus osteotomy Pauwels (1961)	> 300	—	< 27 years	Alle wurden die Beschwerden auf die *Dauer beseitigt*	Die Beweglichkeit nahm in Regel zu	Die Leistungsfähigkeit wurde weitgehend *gesteigert*	
Muscle release op Voss (1956)	72	—	< [illegible] years	Je länger der Eingriff zurückliegt, um so besser ist das subjektive und objektive Befinden. Keine Rezidive			
Küntscher (1958)	> 100	—	—	All but one schlagartige Schmerzfreiheit	—	—	

Treatment	Number of cases		Interval between operation and after examination	Severity of pain	Range of motion	Restriction of function	Patient own assessment
	Operated	After examined					
Voigt (1958)	32	30	< 1 ½ year	Kaum noch verhanden (Deutlich gebessert 15 Etwas erträglicher 8 Unverändert oder verschlechtert 1	Fast frei 1 Deutlich gebessert 11 Wenig verändert 10 Unverändert oder verschlechtert	—	
Voss (1959)	> 300	—	< 7 years	Recht befriedigende Dauerresultate			
Conservative (present material)	92	91	8—1? years	No pain at all 35 % Exc 17 % Good 28 % Fair 11 % Poor 11 %	Exc 3? % Good 37 % Fair 16 Poor 1	Mild 33 Moderate 3 Severe 3?	More severe 17 Unchange 112 Less severe (?) 71

Table 34 *Total material of coxarthrosis (Series C)*

Case No	Fig	Age (years)	Sex	Etiology	Pain: Duration (years)	Pain: Severity	Range of motion	Restriction of function	Localisation	Radiographic severity: 1950—54	Radiographic severity: 1962	Surgery and vital statistics
1171		63	F	0	00	0	80	07	0	1000	1000	1
					08	2	39		2	2130	2230	
1180		68	M	1	28	1	29	09	1	2010	2210	1
					32	1	25		1	3220	3320	
1124		74	M	1	—	—	—	—	0	3331	—	2
					—	—	—		0	3331	—	
3 00		77	F	1	00	0	—	24	0	1000	—	1
					20	1	—		1	2231	—	
14 9	13	68	M	1	00	0	66	06	0	3231	3231	1
					00	0	87		0	1010	1010	
1 10		48	F	1	00(03?)	0	38	07	0	2221	2121	3e
					03	0	38		0	1111	1020	
1582		83	M	1	13	1	18	08	0	3330	3230	3d
					00	0	77		0	0000	1000	
1614		54	F	1	00	0	85	08	0	0000	0000	1
					14	2	25		0	2120	2120	
1374		65	F	2	26	1	03	06	1	2230	2230	1
					00	0	82		0	1000	1000	
2 25		54	M	2	09	0	38	01	0	2120	2230	1
					00	0	70		0	1000	1000	
1181		35	M	2	09	0	59	01	0	1010	1010	1
					00	0	82		0	0000	0000	
1083		18	M	3	00	0	87	01	0	1000	1000	1
					11	0	78		0	1100	2100	
1619		75	M	3	30	5	17	23	1	3330	3230	1
					06	5	11		1	2220	3230	
0319		[illegible]	F	[illegible]	00	0	80	12	0	0000	1000	1
					61	0	00		1	3230	3330	

Code No	Fig	Age (years)	Sex	Etiology	Pain: Duration (years)	Pain: Severity	Range of motion	Restriction of function	Localisation	Radiographic severity 1950—54	Radiographic severity 1962	Surgery and vital statistics
1261		48	F	4	13	1	43	03	0	3221	—	3[a]
					00	0	82		0	0000	0000	—
2509		58	F	5	12	2	68	05	0	1010	1110	1
					12	0	82		2+	0110	0110	
0082		82	M	6	—	—	—	—	1	3221	—	1[c]
					—	—	—		0	1000	—	—
0157		52	M	6	11	0	41	05	2	0110	1110	1
					00	0	78		0	0000	0000	
3236		85	M	6	00	0	69	03	0	2000	2000	1
					17	0	65		0	2011	2101	
0017		80	F	7	—	—	—	—	2	1110	—	2
					—	—	—		2	2210	—	
0019		66	F	7	18	1	23	17	1	1211	3331	1
					01	4	39		1	0000	2210	
0053	14	72	M	7	20	2	03	07	1	3221	3220	1
					00	0	81		0	2000	2000	
0056		72	F	7	32	0	49	13	1	1211	—	1
					00	0	71		0	0000	—	
0081		74	F	7	32	1	37	15	1	2321	3321	1
					00	0	83		0	1000	2000	
0129		79	M	7	00	0	65	09	0	—	2000	1
					20	2	51		1	2100	2221	
0148		69	F	7	—	—	—	—	0	1000	—	2
					—	—	—		0	2100	—	
0165		66	F	7	18	2	42	10	1	231	2131	1
					00	0	81		0	0000	0000	
0166		78	M	7	00	0	72	02	0	2000	2000	1
					12	0	66		0	2110	3110	
0168	15	75	F	7	18	0	17	04	1	21.0	3221	1
					18	0	23		1	2121	2121	

Code No	Fig	Age (years)	Sex	Etiology	Pain		Range of motion	Restriction of function	Localization	Radiographic severity		Surgery and vital statistics
					Duration (years)	Severity				1950—54	1962	
01?4	16	?8	I	7	13 00	1 0	02 77	08	1 0	2110 0000	2330 0000	1
01??		7?	I	7	— —	— —	— —	—	0 1	1000 1100	— —	2
0?01		74	I	7	13 27	5 5	37 37	18	1 1	1100 1100	2221 2221	1
0?31		86	M	7	— —	— —	— —	—	1 0	2221 0000	— —	2
0?48		64	I	7	13 00	0 0	32 68	04	2 0	1110 0000	2?20 0000	1
03?0	1?	71	I	7	30 35	3 2	03 03	15	1 1	2?31 2330	3331 22?0	1
0337		86	M	7	— —	— —	— —	—	0 2	0000 2210	— —	2
0364	18	87	I	7	14 00	0 0	61 79	12	1 0	3321 2000	3221 2000	1
038?		85	I	7	— —	— —	— —	—	1 0	2220 2000	— —	2
0471		63	M	7	14 14	2 0	04 21	11	2 2	2100 3120	3330 3?30	1
04?4		[illegible]	M	7	— —	— —	— —	—	2+ 2	2120 2100	— —	2
0549		94	I	7	— —	— —	— —	—	0 2	1000 2110	— —	2
0568		84	M	7	— —	— —	— —	—	2 0	3120 1000	— —	2
05?9		69	M	7	00 24	0 2	?8 20	09	0 1	1000 2210	2000 3331	1
0?08	19	81	M	7	00 20	0 2	57 41	08	0 1	1000 1110	1000 2331	1

Code N	Fig	Age (year)	Sex	Etiology	Pain		Range of motion	Restriction of function	Localization	Radiographic severity		Surgery and vital statistics
					Duration (year)	Severity				1950—54	1962	
0648		85	M	7	00	0	66	19	0	0000	1000	3^{-}_{f}
					14	2	33		1	12 0	2321	
0651		60	1	7	14	3	38	21	2	2210	—	3bh
					11	1	51½		2	210	2210	—
0680		70	M	7	00	0	80	07	0	0000	1000	3^{-}_{h}
					13	0	43		1	2220	—	
0737		78	M	7	00	0	67	15	0	2000	2000	1
					25		06		1	2110	1220	
0745		82	1	7	—	—	—	—	0	000	—	2
					—	—	—		0	2120	—	
1004		63	1	7	21	1	71	02	2+	2010	2010	1
					00	0	82		0	000	2000	
1031		78	1	7	18	2	44	13	1	2331	—	3^{b}
					00	0	76		0	0000	2000	—
1036		64	M	7	10		41	11	0	2010	2010	1
					15	5	21		2	2110	2110	
1043		68	1	7	11	3	11	16	0	2121	3220	1
					15	3	11		1	11 0	1321	
1054		69	1	7	00	0	46	14	0	0000	1000	3^{-}_{c}
					17	1	62½		0	1010	1110	
1136		72	1	7	—	—	—	—	0	0000		2
					—	—	—		1	2121		
1159		54	M	7	11	0	68½	00	0	1110	1110	1
					00	0	85		0	2010	2000	
1290		61	1	7	00	9	7	06	0	1000	2000	1
					15	2	20		2	21 0	23 0	
1305		80	1	7	—	—	—	—	1	22 0	–	[illegible]
					—	—	—		0	1100		
1311		77	M	7	12	5	27	13	0	2120	3321	1
					00	0	60		0	1100	1100	

Code No	Fig	Age (years)	Sex	Etiology	Pain: Duration (years)	Pain: Severity	Range of motion	Restriction of function	Localization	Radiographic severity 1950—54	Radiographic severity 1962	Surgery and vital statistics
01[illegible]4	16	68	F	7	13 00	1 0	02 77	08	1 0	2110 0000	2330 0000	1
018[illegible]		75	F	7	— —	— —	— —	—	0 1	1000 1100	— —	2
0[illegible]01		74	F	7	13 27	5 5	37 37	18	1 1	1100 1100	2221 2221	1
0[illegible]31		86	M	7	— —	— —	— —	—	1 0	2221 0000	— —	2
0[illegible]8		64	F	7	13 00	0 0	32 68	04	2 0	1110 0000	2120 0000	1
03[illegible]0	17	71	F	7	30 35	3 2	03 03	15	1 1	2231 2330	3331 2220	1
0337		86	M	7	— —	— —	— —	—	0 2	0000 2210	— —	2
0364	18	87	F	7	14 00	0 0	61 79	12	1 0	3321 2000	3221 2000	1
0385		85	F	7	— —	— —	— —	—	1 0	2220 2000	— —	2
0471		63	M	7	14 14	2 0	04 21	11	2 2	2100 3120	3330 3230	1
0474		72	M	7	— —	— —	— —	—	2+ 2	2120 2100	— —	2
0519		94	F	7	— —	— —	— —	—	0 2	1000 2110	— —	2
0568		84	M	7	— —	— —	— —	—	2 0	3120 1000	— —	2
0569		69	M	7	00 24	0 2	78 20	09	0 1	1000 2210	2000 3331	1
0608	19	81	M	7	00 [illegible]0	0 2	[illegible]7 41	08	0 1	1000 1110	1000 2331	1

Code No	Fi	Age (year)	Sex	Etiology	Pain: Duration (year)	Pain: Severity	Range of motion	Restriction of function	Localisation	Radiographic severity: 1950—54	Radiographic severity: 1962	Surgery and vital statistics
1506		96	M	7	—	—	—	—	0	2100	—	2
					—	—	—		0	0100	—	
1541		84	M	[illegible]	—	—	—	—	0	3320	—	2
					—	—	—		0	2110	—	
1554		68	M		—	—	—	—	0	2000	—	2
					—	—	—		0	21?0	—	
1586		87	F	7	11	2	19	17	1	2110	2321	1
					00	0	73		0	1000	1100	
1607	22	83	F	7	?1	2	35	15	1	2?21	2131	1
					00	0	82		0	—	0000	
1637		83	F	7	—	—	—	—	2	2100	—	2
					—	—	—		0	2000	—	
1761		95	M	7	—	—	—	—	0	2000	—	2
					—	—	—		0	1100	—	
1806		81	M	7	—	—	—	—	0	2000	—	2
					—	—	—		1	?2 0	—	
1810		72	F	7	11	1	51	07	0	1110	2?21	3[e]
					00	0	77		0	1000	1000	—
1837		60	F	7	06	0	83	09	0	0110	21?1	3[e]
					00	0	83		0	0000	0000	—
1867		83	M	7	—	—	—	—	0	000	—	2
					—	—	—		1	?3?0	—	
1868		60	M	7	00	0	82	06	0	1000	1000	1
					11	3	50		0	1000	1100	
2018		79	F	7	—	—	—	—	0	1000	—	2
					—	—	—		0	2110	—	
205?		82	F	7	00	0	80	13	0	0000	0000	1
					15	0	50		1	3?21	32?0	
2081		81	M	7	—	—	—	—	1	3330	—	1[b]
					—	—	—		1	3321	—	[b]

Case No	Fig	Age (years)	Sex	Etiology	Pain: Duration (years)	Pain: Severity	Range of motion	Restriction of function	Localization	Radiographic severity: 1950—54	Radiographic severity: 1962	Surgery and vital statistics
134		73	F	7	13	2	03	21	1	1220	3330	1
					00	0	74		0	0000	0000	
2145		83	F	7	10	0	57	12	0	0000	—	1
					15	2	39		1	2220	—	
2185		89	M	7	—	—	—	—	0	1000	—	2
					—	—	—		1	2210	—	
2239		77	M	7	24	4	24	22	1	3231	—	3^{fb}_{ddd}
					15	4	13		1	2210	2330	
[illegible]		64	M	7	17	2	56	06	0	2110	2220	1
					00	0	82		0	2000	2000	
2 9[illegible]		84	M	7	—	—	—	—	0	2320	—	2
					—	—	—		0	0000	—	
2355		81	F	7	—	—	—	—	2	2110	—	2
					—	—	—		0	1000	—	
2365		44	M	7	00	0	63	04	0	1000	1000	1
					13	2	35		1	2220	2321	
2375		68	F	7	00	0	73	01	0	2010	2010	1
					00	0	83		0	0000	0000	
2397		65	M	7	00	0	67	19	0	2000	2000	$\bar{3}_{d}$
					14	2	06		2	2210	2320	
2417		71	M	7	12	3	36	08	1	2110	2220	1
					00	0	73		0	1000	1000	
2427		60	F	7	11	2	31	10	0	2120	3321	1
					01	2	74		0	1010	2010	
2495		76	M	7	14	0	66	06	2	2210	2210	$\bar{3}_{bh}$
					14	0	62		0	2220	—	
2524	23	84	F	7	10	0	18	05	2+	2220	2220	1
					00	0	42		2+	1220	2220	
2531		47	F	7	—	—	—	—	0	2000	—	2
					—	—	—		0	2220	—	

Code No	Fig	Age (years)	Sex	Etiology	Pain: Duration (year)	Pain: Severity	Range of motion	Restriction of function	Localisation	Radiographic severity: 1950—54	Radiographic severity: 196.	Surgery and vital statistics
2536		73	M	7	— —	— —	— —	—	1 0	[illegible]0 2110	— —	2
2560		69	M	7	00 08	0 3	81 37	11	0 2	0000 2120	0000 2120	1
25[illegible]3		79	M	7	— —	— —	— —	—	0 0	2100 1000	— —	2
2606		82	M	7	00 11	0 3	71 42	12	0 0	1000 1210	1000 3321	1
2661		[illegible]9	F	7	— —	— —	— —	—	0 1	1000 2110	— —	2
2691		[illegible]5	M	7	00 13	0 1	$79^{1/2}$ 73	09	0 1	1000 2221	— —	1 th
2699		72	M	7	— —	— —	— —	—	0 0	2010 010	— —	2
2700		73	M		50 70	2 0	09 55	11	1 2	3320 2120	3331 21[illegible]0	1
2818		79	F	7	— —	— —	—		2 2	2010 2010	— —	2
2828		85	M	7	— —	— —	— —		0 2	0000 2220	—	2
2810		65	F	7	34 00	2 2	32 83	04	2+ 0+	2110 1000	2110 0000	1
2841		83	M	7	— —	— —	— —		2+ 2+	2220 2210		2
2882		75	M	7	— —	— —	— —	—	0 0	0000 2210		2
3030		70	M	7	11 00	0 0	00 82	12	1 0	2220 000	[illegible]000	3[illegible]
3037		77	M	7	00 09	0 2	83 50	03	0 0	1000 2120	2000 2220	1

Case No.	Fig.	Age (years)	Sex	Etiology	Pain Duration (years)	Pain Severity	Range of motion	Restriction of function	Localization	Radiographic severity 1950–54	Radiographic severity 1962	Surgery and vital status
131		73	F	7	13	2	03	21	1	1220	3330	1
					00	0	74		0	0000	0000	
14		83	F	7	10	0	57	12	0	0000	—	1
					15	2	39		1	2220	—	
218		89	M	7	—	—	—	—	0	1000	—	2
					—	—	—		1	2210	—	
239		77	M	7	24	4	24	22	1	3231	—	3 fb dd1
					15	4	13		1	2210	2330	
69		64	M	7	17	2	6	06	0	2110	2220	1
					00	0	82		0	2000	2000	
37		84	M	7	—	—	—	—	0	2320	—	2
					—	—	—		0	0000	—	
355		81	F	7	—	—	—	—	2	2110	—	2
					—	—	—		0	1000	—	
2365		74	M	7	00	0	63	04	0	1000	1000	1
					13	2	35		1	2220	2321	
3[illegible]		68	F	7	00	0	73	01	0	2010	2010	1
					00	0	83		0	0000	0000	
2397		65	M	7	00	0	67	19	0	2000	2000	3 d
					14	2	06		2	2210	2320	
2417		71	M	7	12	3	36	08	1	2110	2220	1
					00	0	73		0	1000	1000	
2427		60	F	7	11	2	31	10	0	2120	3321	1
					01	2	74		0	1010	2010	
249		76	M	7	14	0	66	06	2	2210	2210	3 fh
					14	0	62		0	22.0	—	
2 4	23	81	F	7	10	0	18	05	2+	2220	2220	1
					00	0	12		2+	1220	22.0	
3		77	F	[illegible]	—	—	—	—	0	2000	—	2
					—	—	—		0	22 0	—	

Code No	Fig	Age (years)	Sex	Etiology	Pain Duration (years)	Pain Severity	Range of motion	Restriction of function	Localisation	Radiographic severity 1960–61	Radiographic severity 1962	Surgery and vital statistics
3412		54	F	7	09	0	59	01	2	2010	2010	1
					00	0	72		0	1000	1000	
3435		50	M	7	00	0	82	00	0	2000	2000	1
					09	0	73		0	0010	2010	
3455		83	F	7	00	0	77	14	0	1000	1000	1
					15	4	39		1	2220	2131	
3462		79	F	7	10	1	73	26	1	1210	—	3[fbhl he]
					00	0	80		0	0000	0000	—
3480		70	F	7	00	0	80	01	0	1000	1000	1
					09	0	66		0	2110	22 0	
3536		77	F	7	18	1	21	09	1	2220	2231	1
					00	0	75		0	2000	2000	
3571	24	73	M	7	15	4	18	14	1	3221	3221	1
					00	0	86		0	2000	2000	
3609		68	F	7	18	2	03	07	1	2221	2331	1
					00	0	82		0	1000	1000	
3625		80	F	7	00	0	86	17	0	0000	—	1
					19	1	21		1	2220	—	
3646		79	M	7	13	2	32	10	1	22.0	—	3[fb]
					00	0	66		0	2000	2000	—
3653		70	M	7	22	3	0.	11	0	2220	2330	1
					14	3	14		2	22 0	2220	
10,0		80	F	7	—	—	—	—	0	.000	—	2
					—	—	—		1	2221	—	
4267		68	F	7	00	0	83	07	0	1000	1000	3[g]
					08	2	50		1	1110	3221	
4276		83	M	7	—	—	—	—	0	2110	—	2
					—	—	—		1	22 0	—	
4312		78	M	7	—	—	—	—	0	1010	—	2
					—	—	—		1	3221	—	

Case No.	Fig.	Age (years)	Sex	Etiology	Pain: Duration (years)	Pain: Severity	Range of motion	Restriction of function	Localization	Radiographic severity: 1950—54	Radiographic severity: 1962	Surgery and vital statistics
1323		57	F	7	00	0	70	12	0	0000	1000	1
					09	3	12		1	1220	12[illegible]1	
1331		74	F	7	—	—	—	—	0	0000	—	2
					—	—	—		1	2121	—	
13[illegible]		71	F	7	00	0	83	09	0	0000	0000	1
					21	2	11		0	22[illegible]0	2220	
1381		64	F	7	09	2	03	15	1	2110	2331	1
					0[illegible]	3	27		1	2000	2[illegible]20	
1384		66	M	7	09	3	17	14	1	2221	3321	3^{f}
					00	0	$69^{1}/_{2}$		0	2010	2010	
1411		70	M	7	09	0	61	01	1	3331	3121	1
					00	0	72		0	0000	0000	
1415		80	F	7	—	—	—	—	0	2010	—	2
					—	—	—		0	2220	—	
1417		57	F	7	08	2	59	07	2	2110	2120	1
					00	0	80		0	2010	2010	
1447		92	F	7	—	—	—	—	1	2221	—	2
					—	—	—		1	2221	—	
1464		62	F	7	16	0	00	12	1	2220	—	3^{e}
					00	0	79		0	2000	1000	
1477		71	M	7	16	2	18	06	1	3221	3221	1
					00	0	68		0	2110	2110	
14[illegible]8		[illegible]9	M	7	00	0	69	14	0	2110	2110	3^{e}
					14	3	53		0	2220	/ 22[illegible]0	
1486		85	F	7	—	—	—	—	1	2220	—	2
					—	—	—		0	1000	—	
1[illegible]08		80	M	7	—	—	—	—	0	2210	—	2
						—	—		0	2110	—	
[illegible]		82	M	7	00	0	81	14	2	2110	2110	1
					09	2	39		0	2110	23[illegible]0	

Code No	Fig	Age (years)	Sex	Etiology	Pain: Duration (years)	Pain: Severity	Range of motion	Restriction of function	Localization	Rating of the severity: 1950—54	Rating of the severity: 1962	Surgery and vital statistics
4556		82	M	7	10	2	27	18	1	3321	3331	1
					00	0	35		1	2221	2221	
4575		71	F	7	08	1	25	12	2	2110	2110	1
					08	1	29		2	2110	2110	
4610		48	F	7	10	4	03	09	1	2210	3330	1
					05	0	32		1	2000	2220	
4638		96	F	7	—	—	—	—	0	2000	—	2
					—	—	—		1	2230	—	

Symbols

H+ = Hip with the highest counting rate
H — = Hip with the lowest counting rate
Kh+ = Knee on the same side as the hip with the highest counting rate
Kh— = Knee on the same side as the hip with the lowest counting rate
K — = Knee with the lowest counting rate

Table 35 *Coxarthrotic patients studied with external counting of* Sr^{85}

Code No	Case	Activity ratios		
		H+/H—	Kh/Kh—	H/K—
1380	F 11	1 04	1 14	2 53 2 65
0278	F 8	1 59	1 08	1 20 0 76
1036	F 2	1 30	0 99	1 55 1 19
1043	F 20	1 21	0 96	2 38 1 97
1311	F 18	1 87	0 78	1 87 1 00
1335	F 44	1 50	1 31	2 56 1 70
1407	F 12	1 31	0 97	2 81 3 68
1411	F 19	1 28	1 01	2 71 2 12
1436	F 16	3 30	0 83	3 83 1 16
160	F 32	2 67	0 60	3 72 1 39
1868	F 25	5 60	0 28	1 04 5 80
2570	D 100	2 52	0 98	0 62 1 49
3341	F 42	2 83	0 62	2 12 0 89
4323	F 75	2 71	0 83	1 44 3 90

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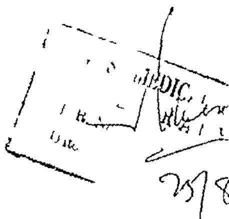
FROM THE ORTHOPAEDIC HOSPITAL OF THE INVALID FOUNDATION
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A SURVEY OF 197 CASES

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CONTENTS

INTRODUCTION AND BRIEF REVIEW OF THE LITERATURE

This paper presents the results of treatment of progressive structural scoliosis in the Orthopaedic Hospital of The Invalid Foundation in Helsinki from 1947 to 1962. The treatment is reviewed on the basis of 197 cases with spinal fusion of the scoliotic spine.

The treatment of structural scoliosis with spinal fusion may soon give way to new surgical methods. Thus A. LANGENSKIÖLD and MICHELSSON produced experimental progressive scoliosis in rabbits and pigs and found that a scoliotic spine can be made to grow straight with soft tissue operations (21, 22, 23). ROAF, in 1962, presented late results of unilateral growth arrest of the spine in scoliosis showing improvement in a considerable proportion (34, 35). GRUCA corrected the scoliotic deformity with springplasty (12) and in 1962 presented good results (13). BLOUNT, in 1962, reported results of treatment with the Milwaukee brace without operation in early paralytic scoliosis and in the treatment of minor idiopathic curvatures nearing maturity; results were gratifying (4, 5). In several cases the brace was worn for five years.

In recent years there has been a fall in the incidence of paralytic scoliosis because of the disappearance of anterior poliomyelitis, perhaps following the introduction of Salk vaccination. The need for spinal fusion will thus be reduced. In spite of this and of all new operative methods, the spinal fusion developed by HIBBS, either in its original form or as modified by others, will retain an important position. In some cases it will remain the best method available, in other instances it may be used as a supplementary procedure. Spinal fusion will keep the corrected spine straight.

There are several excellent papers on the treatment of scoliosis, some of which will be mentioned here because they have guided our choice of treatment. In 1924 HIBBS described his classic technique of spinal fusion (14). In 1931, together with RISSER and FERGUSON, he presented results obtained in 360 cases, also giving indications for fusion (15). These fundamental principles still hold. In 1952 COBB presented his modification of the spinal fusion (9), which has been our main tech-

nique since 1955 In 1954 JAMES classified idiopathic scoliosis into three groups by age at onset (17) In 1950 PONSETI and FRIEDMAN decisively clarified the understanding of the treatment of scoliosis by reporting on 117 cases treated with spinal fusion and by classifying the different curve patterns of idiopathic scoliosis which are important factors to reckon with in planning the treatment and for the prognosis (25, 26) BLOUNT and SCHMIDT made an important contribution by introducing the Milwaukee brace in 1954 (6) In 1958 they presented results of treatment with the Milwaukee brace in combination with spinal fusion (7, 8) In the same year, MOE published his excellent results obtained by spinal fusion In his critical analysis of methods he stressed that a meticulous technique with wide exposure and careful decortication together with fusion of the articular facets is one of the most important conditions of success (24) In the same year, RISSER *et al* presented their material of 347 cases corrected with the turnbuckle body cast and the localizer body cast (33) In 1962, ALVIK (1, 2), THOMASEN (37), and RISKA (27) reported on the treatment of scoliosis in Scandinavia, and at the same time BLOUNT demonstrated nonoperative treatment of some cases of scoliosis with the Milwaukee brace (4) GOLDSTEIN's monograph of 1959 presented the treatment of scoliosis in detail and showed good results (11)

The present addition to the extensive literature on the subject (*cf* also 10, 16, 36 38) is made in the belief that any accumulation of clinical data on scoliosis is likely to yield new details At the same time, the development of the treatment of scoliosis in our clinic will be reviewed and a description given of the method of correction and spinal fusion in use today Some facts are common to all cases, and these will be discussed first

MATERIAL AND METHODS OF TREATMENT

The treatment of structural scoliosis in this clinic was started by the late Professor FABIAN LANGENSKIÖLD and continued since 1956 by ANDERS LANGENSKIÖLD It has followed the lines drawn by HIBBS (14, 15), RISSER (28, 29, 31, 32), COBB (9), and later by BLOUNT and SCHMIDT (6, 7)

Goals of Treatment

The aim of the treatment in idiopathic scoliosis has been to obtain some measure of correction, or at least to prevent further increase of the deformity in the growing child The goal of treatment in paralytic scoliosis has been correction of the existing deformity, prevention of further deformation, and stabilization of a spine that has lost part of its normal muscular support

Material

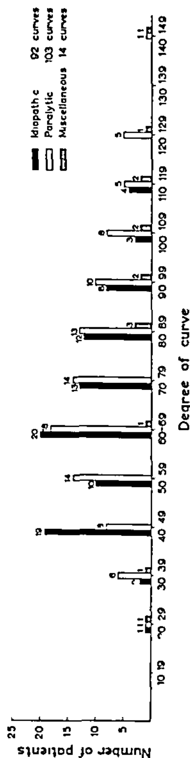
The data are based on analysis of 197 patients having curvatures classified according to PONSETI, FRIEDMAN (25 26) and JAMES (17) as idiopathic, paralytic secondary to poliomyelitis and miscellaneous (Table 1) Sixty four patients out of 86 with idiopathic scoliosis had a

TABLE 1

CLASSIFICATION OF SCOLIOSIS

Scoliosis	No of Cases	Infantile	Juvenile	Adolescent	Main Thoracic Curve	Thoraco-lumbar Curve	Combined Thoracic and Lumbar Curve	Main Lumbar Curve
Idiopathic	86	9	32	45	64	17	5	
Paralytic	99				26	66	6	1
Miscellaneous*	12				4	6	2	
Total	197				94	89	13	1

*Congenital anomaly 5 cases
Neurofibromatosis 3 cases
Scheuermann's disease 1 case
Chondrodystrophia 1 case
Post meningitidem 1 case
Post operationem of congenital heart disease 1 case


Degree of curvature before correction
70 % of curvatures over 60°
Idiopathic 92 curves
Paralytic 103 curves
Miscellaneous 14 curves
Number of patients
Degree of curve
Chart 1

main thoracic curve, and 66 out of 99 cases with paralytic scoliosis had a thoracolumbar curve There were 13 cases with a combined thoracic and lumbar curve, and only one patient had a lumbar curve alone The diagnoses of the miscellaneous cases are given in Table 1

Two hundred and nine curves were corrected and treated with spinal fusion Accordingly, 12 patients had 2 curves to be fused Prior to correction 70 per cent of the curvatures had an angle over 60 (Chart 1)

Correction of Scoliotic Deformity

The turnbuckle plaster cast of RISSER was used from 1947 to 1954 in 42 cases During this period the Milwaukee brace of BLOUNT and SCHMIDT was also employed for some patients since 1954 it has been used as almost a routine measure the total of cases now amounting to 155 (Table 2) In three cases the preoperative correction was made with

TABLE 2

TYPE OF CORRECTION

Correction	Idiopathic	Paralytic	Miscellaneous	Total
The turnbuckle cast of Risser	13	27	2	42
Milwaukee brace of Blount and Schmidt	73	72	10	155

the turnbuckle cast but after surgical intervention the treatment was continued with the Milwaukee brace The turnbuckle body cast increases the angle of both secondary curves, which was one of the motives for our adoption of the Milwaukee brace Because the results of correction with the Milwaukee brace have been good no need has been felt to employ the localizer body cast

Several patients were treated for more than one year with the Milwaukee brace before surgical intervention (Table 3a) depending on the age of the patient at the onset of the deformity, the age of the patient at the beginning of treatment, the degree of the deformity at first examination and also the patient s general condition especially in cases with se

TABLE 3 a

DURATION OF TREAMENT WITH MILWAUKEE BRACE BEFORE THE OPERATION

Time	No of Cases
1 month	33
2 months	22
3 ,,	14
4 ,,	13
5 ,,	8
6 ,,	12
7 ,,	4
8 ,,	3
9 ,,	3
10 ,,	2
12—18 ,	11
18—24 ,	5
2— 3 years	2
3— 4 ,,	6
4— 5 ,,	7
5— 6	5
6— 7 ,,	3
7— 8 ,	2
Total	155

were paralysis after poliomyelitis The tendency to progression was one of the most important factors to reckon with when deciding about commencement of the correction In 33 patients the preoperative treatment with the Milwaukee brace lasted only one month (Table 3a), which sufficed to familiarize the patient with the brace The treatment with the Milwaukee brace after spinal fusion was continued for 9 months in 45 patients, 10 months in 34 and 11 months in 22 patients In 32 cases this treatment was continued for more than one year (Table 3b)

TABLL 3 b

DURATION OF TREATMENT WITH MILWAUKEE BRACE AFTER THE OPERATION

Time (months)	No of Patient	Pat nts with Pseudarthroses
5—8	9	0
9	45	10
10	34	10
11	22	5
12	15	4
13	8	2
14	4	0
15	2	0
16	2	1
18	1	0
more than 19	15	8
Total	157	40

Patients with the turnbuckle body cast were operated on through a large posterior window in the plaster cast The Milwaukee brace was removed before the operation and reapplied after the spinal fusion on the same day or in some cases on the day after the operation In the patients treated with the turnbuckle cast the correction was obtained prior to the operation in the patients with the Milwaukee brace correction continued during 10 days after the operation

The results of correction with the Milwaukee brace were satisfactory (Tables 13—19) and when carefully fitted, the brace was well tolerated by the patient Out of 45 patients treated with the Milwaukee brace during 9 months after the operation 10 (22 per cent) had pseudarthroses in the fusion area and out of 22 patients treated with the brace during 11 months 5 (22 per cent) had pseudarthroses (Table 3b)

Sex and Age at Time of Surgical Intervention

The distribution of patients by age and sex is shown in Chart 2 The age of patients at the time of fusion varied from 8 to 29 years Most of the patients (65 per cent) were operated on at an age of 12 to 15 years

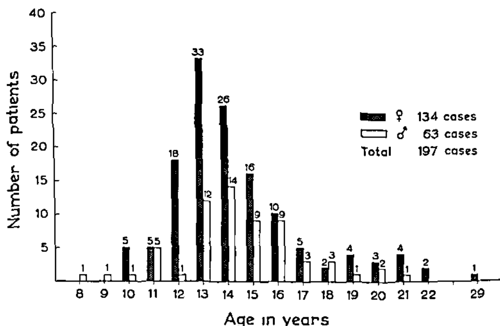


Chart 2

Risser in 1958 reported on the time of fusion of iliac apophyses by the age of patients stating that the vertebral growth is completed near the time when iliac apophyses are attached to the iliac crest (30) Like Risser we have noted that at least in idiopathic scoliosis the deformity no longer progressed when the growth of the spine was completed The progression could, however continue in patients with severe paralysis after poliomyelitis, which agrees with reports presented before (11, 24, 30) The development and fusion of iliac apophyses were examined and followed in most cases The fusion took place earlier in girls than in boys (Table 4) in 47 girls it was completed at 16 years, and in 22 boys

TABLE 4

LATERAL FUSION OF ILIAC APOPHYSES
CORRELATED WITH THE AGE OF PATIENTS

Age at Fusion of Apophyses	Girls	Boys	Total Patient		Patients with Pseudarthroses	
			No of Cases	Average Age at Surgery	No of Cases	Average Age at Surgery
Years	No of Cases	No of Cases		Years and Months		Years and Months
14	15	1	16	12 3	2	10 4
15	32	6	38	13 7	10	13 5
16	47	18	65	14 2	19	13 8
17	10	22	32	15 8	10	14 2
18	4	6	10	16 6	4	16 6
19	0	2	2	20 1	2	20 1
20	1	1	2	18 1	1	19 2
No apophyses	10	5	15	12 4	5	11 10
Unknown	15	2	17	18 3	4	16 9
Total	134	63	197		57	

at 17 years Skeletal age was determined only in some cases though today we recognise its importance in the planning of treatment

A classification of the patients with postoperative pseudarthroses into age groups shows that the number of cases with pseudarthroses was greater in patients with a longer growth period of the spine or in patients with a late fusion of the iliac apophyses (Table 4) Correspondingly there was major loss of correction in 9 cases and pseudarthrosis in 5 cases out of 19 operated on at a calendar age of 12, but major loss of correction in only 4 and pseudarthrosis in only 3 out of 19 patients operated on at a calendar age of 16 years It therefore seems wise to postpone the time of surgical intervention The development of iliac apophyses and vertebral growth must be closely watched though the degree of the deformity and its progression are the most important factors in deciding the time for surgical intervention

Operative Technique

Three general types of fusion were employed by about 20 different surgeons (Table 5) First, the original HIBBS method with fusion of articular facets was used in 23 cases until 1954—1955 One patient developed paraplegia on account of the operation, and destruction of articular facets was discontinued when the operation was done to 24 patients in 1955—1956 The clinical results were disappointing because of major loss of correction Therefore, since 1955—1956, in the majority of cases the fusion was carried out by the COBB modification by adding substantial amounts of bone grafts into the fusion area Until 1959, homogenous bone bank bone was mostly used, altogether in 96 patients, but the number of cases with pseudarthroses was high Therefore since 1959 most of the fusions have been done with autogenous bone grafts (40 patients), or with autogenous bone together with bank bone (14 patients) In 29 cases solely tibial bone and in 11 cases solely fresh ilium was used as grafting material (Table 5) In 22 out of 54 patients the autogenous bone was taken prior to the spinal fusion, banked and used 2 weeks

TABLE 5

TYPE OF FUSION

Fusion	Idiopathic	Paralytic	Miscellaneous	Total
Hibbs type fusion with articular facets fusion	4	19		23
Without articular facets fusion No bone added	8	15	1	24
Cobb type fusion Bone bank bone added	50	39	7	96
Cobb type fusion Autogenous tibial bone added	13	12	4	29
Cobb type fusion Autogenous ilium added	4	7		11
Cobb type fusion Bone bank bone and autogenous bone added	7	7		14

later for fusion In 32 cases the autogenous bone was taken at the same operation and transplanted at once

Out of 22 patients from whom the bone was taken two weeks before the spinal fusion 3 (14 per cent) had pseudarthroses in the graft out of 32 patients with fresh bone grafts transplanted at the same operation 4 (13 per cent) had pseudarthroses It seems better to transfer the bone afresh though the operation takes more time Only one anesthesia is needed for a spinal fusion in one stage

In 117 patients the operation was done in one stage (Table 6) in 70 in two, and in 10 in 3 stages Altogether 287 operations were carried out on 197 patients

The patients were kept in bed for 4 months after the operation

TABLE 6

NUMBER OF OPERATIONS

Scoliosis	No. of Cases	No. of Operations			
		1	2	3	Total
Idiopathic	86	63	19	4	113
Paralytic	99	45	49	5	158
Miscellaneous	12	9	2	1	16
Total	197	117	70	10	287

Complications

There were 2 patients with paraplegia on account of the operation One was a case of paralytic the other of idiopathic scoliosis In the second patient the fusion area and the spinal cord were explored 60 days after the spinal fusion but without any positive findings There was one death of uraemia secondary to glomerulonephritis after thoracoplasty which was the third operation for this patient One patient died at home of congenital heart disease thirteen months after the operation Another patient died also at home two years after the operation from infection of the respiratory tract but she suffered from severe paralysis after poliomyelitis and had a high degree scoliotic deformity Thus there were 3 patients with serious complications on account of the operation

RESULTS OF TREATMENT

A complete roentgenographic survey of the scoliotic spine was carried out, including anteroposterior roentgenograms made with the patient supine, standing, and bending to the right and to the left. Later, oblique roentgenograms were taken to evaluate the stability of the fused area. During the whole period the COBB method of measurement of the scoliotic deformity was used (Table 7). According to this method, the scoliotic angulation is the angle formed by the intersection of lines drawn perpendicular to the superior surface of the top vertebra and the inferior surface of the lowest vertebra of the curve.

TABLE 7

MEASUREMENT OF SCOLIOTIC DEFORMITY
COBB'S METHOD

A. **Precorrection curvature**: maximum curvature with the patient **standing**.
B. **Corrected curvature**: minimum curvature after correction with the patient **supine**.
C. **Final curvature**: measurement at the last follow-up examination with the patient **standing**.

Correction	(degrees)	$= A - B$
	(per cent)	$= \frac{A - B}{A} \times 100$
Loss of correction	(degrees)	$= C - B$
	(per cent)	$= \frac{C - B}{A - B} \times 100$
Net correction	(degrees)	$= A - C$
	(per cent)	$= \frac{A - C}{A} \times 100$
Progression	(degrees)	$= C - A$
	(per cent)	$= \frac{C - A}{A} \times 100$

The majority of the patients were followed up postoperatively for more than three years (Table 8) The mean duration of the follow up period was over 4 years and for 57 patients over 6 years The data were obtained by the author s personal evaluation at the follow up examination of patients treated in this hospital

A partial correction of the scoliotic deformity can be achieved with the turnbuckle plaster cast with the localizer body cast or with the Milwaukee brace Today correction of a scoliotic deformity to an acceptable state is no longer a problem except in imbalanced patients with a great deformity The greatest difficulty is to maintain the correction If this can be done, a good result will be achieved MOE in 1958 stressed the importance of a good operative technique (24) but even then the correction can be lost The existence of pseudarthroses in

TABLE 8

TIME FROM OPERATION TO LAST FOLLOW UP EXAMINATION

Time	No. of Cases
3—12 months	2*
12—18	26
18—24 ,,	25
2— 3 years	30
3— 4	21
4— 5	17
5— 6	19
6— 7	24
7— 8	12
8— 9	5
9—10	10
10—11	3
11—12 ,,	3
Total	197

* One death and one paraplegia

the grafts of the fused spine must be regarded as one of the main reasons for the loss of correction and for the progression of the scoliotic deformity after spinal fusion Therefore it is worth while to try to diagnose these pseudarthroses at an early stage

Incidence of Pseudarthroses

It is not always easy to find a pseudarthrosis in the fusion area of the spine Roentgenograms made with the patient bending to both sides are imperative together with oblique exposures In several cases in our clinic, tomography has been used Patients with pseudarthroses have pain in the back mainly in the fusion area, and all of them complain of back fatigue after strain especially in the evening Pseudarthrosis leads to movement in the fusion area, and a crack can be heard when the patient is bent sidewards *If there is a real pseudarthrosis, most or all of the correction achieved will be lost*

No major difference existed in the rate of pseudarthroses between patients with idiopathic scoliosis (24 cases out 86 patients 28 per cent) and those with paralytic scoliosis (32 cases out of 99 patients, 32 per cent) Altogether there were 57 patients with pseudarthroses causing symptoms in 197 operated cases which makes 29 per cent (Table 9) More pseudarthroses were found roentgenologically (in 81 patients 45 per cent), but only 57 of them manifested all the clinical symptoms of a real pseudarthrosis Of patients treated with spinal fusion without addition of supplementary bone to the fusion area, 40 per cent developed pseudarthroses in patients with bank bone as supplementary graft pseudarthroses occurred in 32

TABLE 9

INCIDENCE OF PSEUDARTHROSIS

Scoliosis	Cases	Pseudarthrosis		Became Solid	Still Persisting
		No	Per cent		
Idiopathic	86	24	28	14	10
Paralytic	99	32	32	20	12
Miscellaneous	12	1			1
Total	197	57	29	34	23

per cent (Table 10) Only 5 (13 per cent) of the patients treated with fusion with the addition of autogenous bone had pseudarthroses when autogenous bone was used together with bank bone, pseudarthroses were found in 2 cases (14 per cent) Accordingly autogenous bone must be regarded as superior to bone bank bone as a grafting material a principle known for some years (3 24)

In 30 patients the pseudarthroses became solid with prolonged use of the Milwaukee brace (Table 9) Only in four cases were the pseudarthroses surgically treated

TABLE 10

INCIDENCE OF PSEUDARTHROSIS
IDIOPATHIC PARALYTIC AND MISCELLANEOUS SCOLIOSIS

Type of Bone Added	Cases	Pseudarthroses	
		No	Per cent
No bone added	47	19	40
Bone bank bone	96	31	32
Autogenous bone	40	5	13
Bone bank bone and autogenous bone	14	2	14
Total	197	57	29

Causes of Loss of Correction in 68 Patients

There was a major loss of correction in 68 patients (Table 11) In 46 patients a pseudarthrosis in the fusion area was responsible In 12 out

TABLE 11

CAUSES OF MAJOR LOSS OF CORRECTION IN 68 CASES

	No of Cases	Pseudarthroses	Fusion Area not of Adequate Length	Loss of Correction in Spite of Solid Fusion of Adequate Length
Idiopathic	30	21	6	3
Paralytic	35	25	5	5
Miscellaneous	3		1	2
Total	68	46	12	10

of 68 patients with a major loss of correction after the operation the fusion area was of inadequate length and in 10 cases no clear reason could be established Unrelenting bending force acting upon the fused spine could perhaps cause such a loss of correction In 37 out of the 68 patients with a major loss of correction, bank bone had been added to the fusion area *and in 20 patients no bone had been added at all (Table* 11)

Good Results in 63 Patients

The result of treatment was classified as good if the loss of correction was less than about 15 degrees and if the net correction was about 20 per cent No pseudarthroses were found in the fusion area and the cosmetic result corresponded to the correction achieved

A good result was obtained in a total of 63 out of 197 patients (Table 12) comprising 19 (48 per cent) out of the 40 patients treated with autogenous bone as supplementary graft A good result was gained only in 25 cases (26 per cent) out of the 96 patients fused with the addition of bank bone These 63 patients had an average net correction of 23 per cent which corresponds to the good cosmetic results

TABLE 12

SIXTY THREE CASES WITH GOOD RESULT OF TREATMENT CORRELATED WITH THE TYPE OF BONE ADDED

Type of Bone Added	No of Cases	Average Net Correction	
		Degrees	Per cent
No bone added	10 out of 47	21	22
Bone bank bone added	25 out of 96	15	22
Autogenous bone added	19 out of 40	16	24
Autogenous bone and bone bank bone added	9 out of 14	16	24
Total	63 out of 197	16	23

Idiopathic Scoliosis

The results of treatment with spinal fusion are given in Tables 13—15. In the last years the fusions have been done mostly with supplementary autogenous bone or autogenous bone together with bank bone. In these two groups of patients (17 and 7 patients) the average net correction was between 10 and 26 per cent and only in 2 patients did a pseudarthrosis occur in the graft. Sixteen out of 50 patients grafted with supplementary bone bank bone had pseudarthroses, the average net correction being between 7 and 10 per cent. These results leave a great deal to be desired, especially when compared with statistics presented before (7, 11, 24) but it must here be repeated that the operations were performed by 20 different surgeons. Patients treated privately had better results but are not considered separately in this study. The average maximum correction of the scoliotic deformity was good (Tables 13—15) but the loss of correction too great, even though the corrected curvature was measured from a roentgenogram made with the patient supine and the final curvature at the last follow up examination with the patient

TABLE 13

IDIOPATHIC SCOLIOSIS
PRECORRECTION CURVATURE UNDER 50
CORRECTION OBTAINED FOLLOWING SURGERY

Type of Fusion and of Bone Added	Time of Operation	No. of Cases	Average Maximum Correction		Average Loss of Correction		Average Net Correction		No. of Pseudarthroses
			Degrees	Per cent	Degrees	Per cent	Degrees	Per cent	
Hibbs type fusion with articular facets fusion									
Without articular facets fusion. No bone added	1955	1	26	65	17	65	9	22	0
Cobb type fusion. Bone bank bone added	1955-1961	10	19	45	15	89	4	7	3
Cobb type fusion. Autogenous bone added	1960-1961	4	20	42	8	40	12	26	0
Cobb type fusion. Bone bank bone and autogenous bone added	1959-1960	2	21	48	16	76	5	11	1
Total		17							4

TABLE 14

IDIOPATHIC SCOLIOSIS
PRECORRECTION CURVATURE BETWEEN 50 80°
CORRECTION OBTAINED FOLLOWING SURGERY

Type of Fusion and of Bone Added	Time of Operation	No of Cases	Average Maximum Correction		Average Loss of Correction		Average Net Correction		No of Pseudarthroses
			Degrees	Per cent	Degrees	Per cent	Degrees	Per cent	
Hibbs type fusion with articular facets fusion	1954	1	12	22	12	100	0	0	1
Without articular facets fusion No bone added	1953-1955	5	25	43	23	91	2	3	3
Cobb type fusion Bone bank bone added	1955-1961	24	26	40	19	70	7	10	8
Cobb type fusion Autogenous bone added	1955-1961	8	24	37	15	65	9	11	0
Cobb type fusion Bone bank bone and autogenous bone added	1959-1961	4	31	47	15	49	16	26	0
Total		42							12

TABLE 15

IDIOPATHIC SCOLIOSIS
PRECORRECTION CURVATURE OVER 80°
CORRECTION OBTAINED FOLLOWING SURGERY

Type of Fusion and of Bone Added	Time of Operation	No of Cases	Average Maximum Correction		Average Loss of Correction		Average Net Correction		No of Pseudarthroses
			Degrees	Per cent	Degrees	Per cent	Degrees	Per cent	
Hibbs type fusion with articular facets fusion	1952-1954	3	6	7	6	100	0	0	1
Without articular facets fusion No bone added	1953	2	17	20	14	76	3	5	1
Cobb type fusion Bone bank bone added	1954-1961	16	28	31	19	67	9	10	5
Cobb type fusion Autogenous bone added	1955-1961	5	27	29	17	66	10	10	0
Cobb type fusion Bone bank bone and autogenous bone added	1955	1	54	61	54	100	0	0	1
Total		27							8

standing. The development of pseudarthroses and the consequent loss were probably often caused by an operative technique with poor exposure and poor decortication, or arose as a result of grafting with bank bone. Regarding the degree of the deformity, the pseudarthrosis rate was almost the same in all three groups of patients (precorrection curve under 50°, between 50 and 80°, and over 80°): in the first group it was 2[illegible] per cent, in the second 29 per cent, and in the third 29 per cent (Table [illegible]).

Paralytic Scoliosis

The results are given in Tables 16—18. Percentual [illegible] maximum correction was almost the same in all three groups of patients with precorrection curves under 50°, between 50 and 80°, and over 80°. The average loss of correction was great in all three groups, being greatest in patients with precorrection curves under 50°. The [illegible] average net corrections were gained in patients with precorrection curvatures over 80° treated with the original Hibbs type fusion (Table 18). The average net corrections were 9, 13 and 10 per cent in patients treated with supplementary autogenous bone, but only 3, 12 and 6

TABLE 16

PARALYTIC SCOLIOSIS
PRECORRECTION CURVATURE UNDER 50
CORRECTION OBTAINED FOLLOWING SURGERY

Type of Fusion and of Bone Added	Time of Operation	No. of Cases	Average Maximum Correction		Average Loss of Correction		Average Net Correction		No. of [illegible]
			Degrees	Per cent	Degrees	Per cent	Degrees	Per cent	
Hibbs type fusion with articular facets fusion	1952-1953	3	13	27	12	99	1	2	3
Without articular facets fusion. No bone added	1953	1	18	47	18	100	0	0	1
Cobb type fusion. Bone bank bone added	1955-1960	8	15	40	14	93	1	3	2
Cobb type fusion. Autogenous bone added	1955-1961	3	18	47	14	84	4	9	1
Cobb type fusion. Autogenous bone and bone bank bone added									
Total		15							7

TABLE 17

PARALYTIC SCOLIOSIS
PRECORRECTION CURVATURE BETWEEN 50 80°
CORRECTION OBTAINED FOLLOWING SURGERY

Type of Fusion and of Bone Added	Time of Operation	No. of Cases	Average Maximum Correction		Average Loss of Correction		Average Net Correction		No. of Pseudarthroses
			Degree	Per cent	Degrees	Per cent	Degree	Per cent	
Hibbs type fusion with articular facets fusion	1951-1953	6	22	26	21	97	1	2	3
Without articular facets fusion No bone added	1953-1956	7	18	31	14	80	4	6	2
Cobb type fusion Bone bank bone added	1955-1961	17	28	42	20	70	8	12	8
Cobb type fusion Autogenous bone added	1955-1961	10	27	39	19	70	8	13	3
Cobb type fusion Autogenous bone and bone bank bone added	1960-1961	5	27	39	15	58	12	17	0
Total		45							17

TABLE 18

PARALYTIC SCOLIOSIS
PRECORRECTION CURVATURE OVER 80°
CORRECTION OBTAINED FOLLOWING SURGERY

Type of Fusion and of Bone Added	Time of Operation	No. of Cases	Average Maximum Correction		Average Loss of Correction		Average Net Correction		No. of Pseudarthroses
			Degree	Per cent	Degrees	Per cent	Degree	Per cent	
Hibbs type fusion with articular facets fusion	1951-1955	10	44	42	25	58	19	18	1
Without articular facets fusion No bone added	1951-1955	7	35	36	27	66	8	9	2
Cobb type fusion Bone bank bone added	1955-1961	14	33	32	26	77	7	6	4
Cobb type fusion Autogenous bone added	1960-1961	6	32	32	23	75	10	10	1
Cobb type fusion Autogenous bone and bone bank bone added	1955-1958	2	28	29	20	74	8	8	0
Total		39							8

per cent in patients treated with bank bone (Tables 16—18). Only 5 patients out of 26 grafted with autogenous bone or with autogenous as well as bank bone had pseudarthroses. On the other hand 14 patients out of 39 treated with supplementary bank bone had pseudarthroses. According to this good results should be obtained with the original Hibbs type fusion using autogenous bone as grafting material which corresponds to the technique described by Moe (24). Seven patients (47 per cent) out of 15 with precorrection curvatures under 50° had pseudarthroses. When the precorrection curvature was between 50° and 80°, pseudarthroses occurred in 17 out of 45 (38 per cent) and when the precorrection curvature exceeded 80° the pseudarthrosis rate fell to 8 out of 39 (21 per cent). The patients with precorrection curvature over 80° were older when operated. Results thus improve when the time of surgical intervention approaches the time when vertebral growth is nearing completion (see above).

Miscellaneous Cases

The results are given in Table 19. The correction of the scoliotic deformity in 11 patients was good. The loss of correction averaging

TABLE 19

MISCELLANEOUS CASES OF SCOLIOSIS
CORRECTION OBTAINED FOLLOWING SURGERY

[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Hibbs type fusion with articular facets fusion									
Without articular facets fusion. No bone added	1955	1	10	9	1	10	9	8	0
Cobb type fusion. Bone bank bone added	1955-1961	7	31	26	24	80	7	10	1
Cobb type fusion. Autogenous bone added	1959-1961	4	29	34	19	47	10	15	0
Cobb type fusion. Autogenous bone and bone bank bone added									
Total		12							1

80 per cent in the 7 patients treated with supplementary bank bone is an unfortunate demonstration of the inferiority of this grafting material to autogenous bone None of the 4 patients treated with autogenous bone had pseudarthroses, and the average net correction amounted to 15 per cent One patient had a pseudarthrosis in the graft In this case the fusion was done with supplementary bank bone

Cosmetic Results

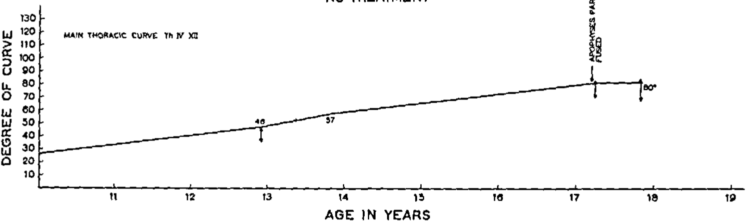
In judging the end results of treatment, the cosmetic result is as important as roentgenographic evidence of a corrected curvature Compensation can be regained and the patient s appearance improved without roentgenographic evidence of correction but in general a good cosmetic result indicates an improvement also demonstrable roentgenographically On the other hand, a good correction of the deformity can give a poor cosmetic result with a column difficult to keep in balance Therefore the surgeon s evaluation of the cosmetic result as well as the opinions of the patient and of the parents are important To facilitate analysis of the development of the deformity, almost all patients were routinely photographed before, during and after treatment The 63 patients with a net correction of 23 per cent had a good cosmetic result (Table 12) Most patients with a major loss of correction following spinal fusion of inadequate length showed a poor cosmetic result, some of them being still out of balance after treatment (Table 11) In 22 patients with pseudarthroses causing loss of correction or even a progression of the deformity, the cosmetic result was poor (*c f* Table 11)

Degree of Deformity During Treatment

Graphic illustration facilitates evaluation of the total constellation of factors connected with the treatment and the development of the deformity It should be noted that only the corrected curvature was measured from a roentgenogram made with the patient supine all the others were determined with the patient standing The graphic presentation accounts for the following data the degree of the angle of the scoliotic deformity at the time of examination, the age of the patient the time of commencement of treatment with the Milwaukee brace the time when the brace was taken off the time of surgical intervention the type of bone added the period

of recumbency after the operation, the time of fusion of iliac apophyses and the follow-up period with the time of last examination. The photographs and roentgenograms below the graphs illustrate the patient's condition before and after treatment. Together with 9 cases treated with spinal fusion, three untreated cases are presented graphically, two having juvenile and one infantile idiopathic scoliosis. These three unoperated patients may serve as points of reference in the advising of surgical treatment, e.g. spinal fusion, in progressive structural scoliosis. At an early date they will develop complications and cardiopulmonary trouble (cf. 20) which of course must be avoided. The graphs may also throw light on the progress of the scoliosis and on the patient's prognosis which are difficult to estimate at an early stage. Comparison of the results of surgery with the condition of these three untreated patients suggest that there is reason enough to continue with spinal fusion until a better and/or simpler method of treatment has been developed.

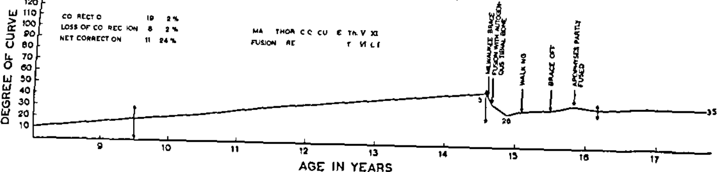
Patients 1 (Fig. 1) and 5 (Fig. 5) were untreated. Patients 2—4 (Figs. 2—4) are cases of idiopathic scoliosis. Patients 2 and 4 had good and patient 3 fair results of treatment, without which a condition like that of Patient 1 could have developed. Patient 6 (Fig. 6) is also a case of idiopathic scoliosis treated with a good result. A condition like that of Patient 5 might have developed without adequate treatment. Patient 7 (Fig. 7) had juvenile idiopathic scoliosis and was given sufficiently early treatment with the Milwaukee brace until the time of surgical intervention, when the parents refused the operation. Treatment was discontinued and the deformity progressed to 142°. Patients 8 (Fig. 8) and 9 (Fig. 9) are cases of adolescent idiopathic scoliosis treated adequately and with good results. Patient 10 (Fig. 10) illustrates a case of idiopathic scoliosis treated early and with good correction of the deformity but with a major loss of correction on account of development of pseudarthroses in the fusion area. The pseudarthroses were treated with prolonged use of the Milwaukee brace. Patient 11 (Fig. 11) also illustrates a case with a major loss of correction and with progression of the scoliotic deformity during treatment. The fusion area was explored but no pseudarthroses could be found. In spite of early treatment continued postoperatively with prolonged use of the Milwaukee brace, the result was poor. Without surgery the deformity might have grown even beyond the 55° found at the last follow-up examination. Patient 12 (Fig. 12) is a case of paralytic scoliosis with a good result of treatment. The fusion was done with supplementary autogenous iliac bone.





l c d

the scoliotic spine The patient was out f balance



a b c

Fig 6 Patient 6 a —Before treatment b — Corrected curvature c and d — the good cosmetic result

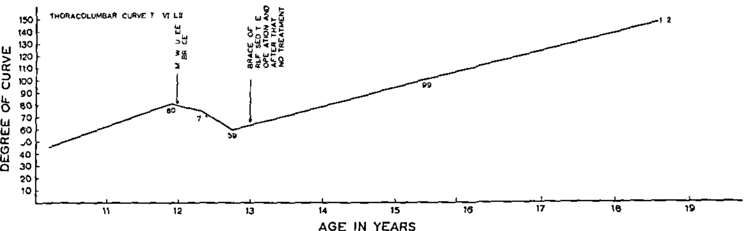
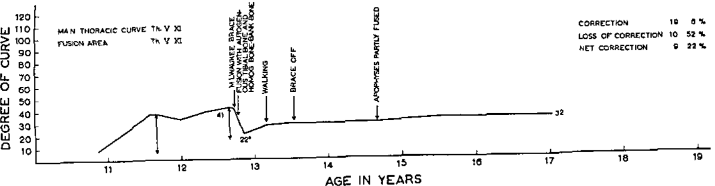


Fig 7 Patient 7 a — Before treatment c — A correction of 21 was achieved with the M... parents refused the operation and discarded the brace which resulted ... Note the severe deformity at last examination



a b c d e

Fig 8 Patient 8 a and b — Before treatment c — Four months after operation d and e — At last follow up examination Good result of treatment



a b c d

Fig. 9 Patient 9. Before treatment. Note that the patient is out of balance. c and d — At last follow up examination. Good result of treatment.

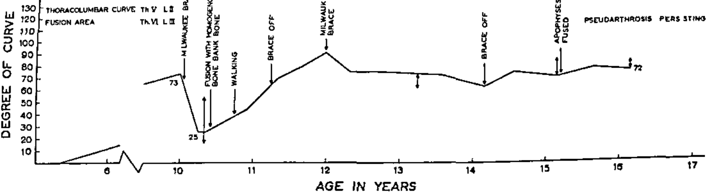
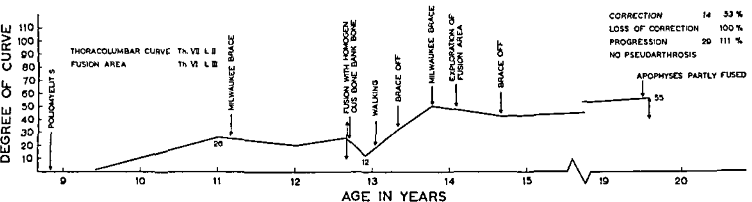
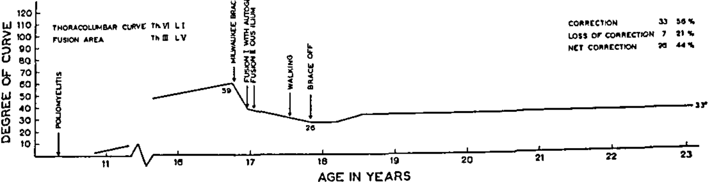


Fig 10 Patient 10 a and b — before treatment c and d — At last follow up examination The correction was good but the loss of correction was 97 per cent on account of the development of pseudarthroses These were treated with prolonged use of the Milwaukee brace The result of treatment was poor



a b c d e f

Fig 11 Patient 11 a and b — Before treatment c — Corrected curvature d — Deformity at the time when the brace was taken off e and f — At last follow up examination Because of progression of the deformity the fusion area was explored but no pseudarthrosis could be found The result of treatment was poor



a b c d

Fig. 12 Patient 12 a and b — Before treatment c and d — At last follow up examination The result of treatment was good

PRESENT METHOD OF TREATMENT

During the early years of treatment of scoliosis, cases with advanced deformities were frequently seen in Finland, and few therapeutic measures were taken to improve their condition. Such advanced deformities have become much rarer. They are seldom met with today, especially among patients who have profited from the present trend towards early treatment begun as soon as the curvature reaches an angle of 40—50°.

Correction of Scoliotic Deformity

The severity of the deformity determines the onset of treatment with the Milwaukee brace irrespective of the patient's age. The brace is built according to the specifications of Blount and Schmidt, and during its fitting the patient is hospitalized for a few days to confirm a good fit and to ensure that the brace is well tolerated (Fig. 13).



a b c

Fig. 13. Milwaukee Brace

Parents are personally consulted, shown how to put on and take off the brace, and given detailed instructions as to its use. W[illegible] adequate training the patients learn to wear it on all occasions [illegible]

Time of Surgical Intervention

The degree of the deformity together with the patient's [illegible] and general condition determine the time for operative [illegible] the deformity increases in spite of the treatment with the brace [illegible] is undertaken. Otherwise one may wait for an increase of skeletal ma[illegible]rity or until appearance of the iliac apophyses. It is however frequently necessary to intervene earlier, as early as at 12 or 14 years of age, if the deforming curvature attains an angle of 40° to 50°. Today the sk[illegible] age is routinely determined and followed in every patient. Owing to their more advanced skeletal maturation, girls are operated on earlier than boys.

Determination of Fusion Area

In cases with three scoliotic curves the middle or primary one is selected for fusion. When there are two primary curves the upper or both are fused. In idiopathic scoliosis the entire primary curvature from its top vertebra to the bottom one is fused. In paralytic scoliosis, the fusion is preferably extended one vertebra beyond the primary curve in both directions, the patient's balance permitting. Balance is one of the most important considerations in selecting the fusion area. In this respect, each case offers its own problems and no general rules can be given. Attention must be paid to the length of the extremities, the position of the pelvis and the function of the joints, which all affect the determination of fusion length especially in patients with poliomyelitis. Generally, the area to be fused at one time comprises 5—8 vertebrae. Thus if the curvature extends over a long region the fusion must be carried out in two or even three stages.

Operative Technique

The brace is removed for the operation and replaced on the same or the following day. Tibial or iliac grafts are taken, if possible at the same operation. Tibial grafts have proved as good as iliac ones providing that enough cancellous bone is taken from the tibial condyle. The con

dition of the iliac donor site may disturb postoperative treatment with the Milwaukee brace, but in severe poliomyelitic cases it is not always possible to get bone grafts from the tibia The operation is carried out by means of the COBB modification of spinal fusion with meticulous soft tissue excision and liberation and a wide exposure of the fusion area Spinous processes are cut down Vertebral laminae and, if possible, transverse processes are carefully decorticated with a razor sharp hand gouge, the raised bone flaps being placed down next to each other over the fusion area the transverse end attached Use of the mallet is avoided Almost always the procedure is easily carried out on both sides providing that there is not too much rotational deformity The operation does, however take time The fusion area is first covered with cancellous bone taken from the tibial condyle or from the ilium Then, cortical bone grafts of suitable length and width either from the tibia or from the outer table of the ilium are placed over the entire fusion area mainly on the concavity It is important that the tibial grafts are long enough and extend over the entire curvature to be fused The extension of the Milwaukee brace involving the final correction is carried out during 10 days after the operation Thereafter the brace must be well fitted The patient is kept in bed for four months postoperatively

Postoperative Treatment with the Milwaukee Brace

The patient visits the clinic once every two months for follow up examinations, at which the condition and fit of the brace are inspected If necessary, the brace is repaired or extended The brace will be worn until the fusion is solid, and if indicated, until vertebral growth is completed The patient is allowed to return to school one month after the end of the period of recumbency Use of the brace is gradually discontinued some 9 months after operation, and for the final month or two it is worn only by night The brace has been found to cause dental protrusion This usually calls for no further m ures, as follow ups have shown that in most patients the p teeth spontaneously return to their normal positions after the b is given up Very long postoperative treatment with the brace necessitate dental prosthesis

Roentgen Examinations and Photographs of the Patient

Roentgenography with the techniques described above is carried out with 2—5 month intervals before surgery, immediately before the operation and postoperatively after one month, at the end of hospitalization, and at follow ups with 2—5 month intervals until the definitive end of treatment The patient is photographed before onset of treatment, preoperatively wearing the Milwaukee brace, at the end of the brace wearing period some 9 months after surgery, and at the final follow up examination Further pictures are taken as suggested by changes in the deformity during treatment

Search for Pseudarthroses

Before the patient leaves hospital some 4 months after the operation, the search for pseudarthroses is begun with roentgenography of the fusion area Found pseudarthroses can be repaired surgically, if necessary Renewed roentgenography at the end of the brace wearing period usually reveals possible pseudarthroses Roentgenograms made with the patient bending as well as oblique views are imperative, and tomography is helpful Clinical examination is no less important (see above)

Treatment of Pseudarthroses

When pseudarthrosis has been found to cause loss of correction surgical repair is indicated When a found pseudarthrosis has not caused loss of correction, treatment with the Milwaukee brace is continued until consolidation or until the iliac apophyses have fully developed After this the deformity usually does not increase irrespective of the consolidation of the pseudarthrosis If the deformity goes on increasing, treatment with the brace must be resumed or the pseudarthrosis repaired by surgery The fusion area is explored and the pseudarthrosis resected and repaired with fresh autogenous bone grafts

Follow up Examinations and After Care

All patients must undergo regular follow up examinations until the growth of the spine is completed In several instances follow ups have been carried out over many years Even after treatment proper is con

cluded, there are various social motives for regular examinations, say once a year for several years Possible permanent disabilities are registered in the course of the follow up, and special attention is paid to the patient's education and training In Finland, all scoliotic patients aged 16 are, if indicated, given a full trade school course free of charge Follow ups are thus suggested by, and carried out in connection with, the patient's education and training for a profession or trade The aim both of treatment and of schooling is to turn the scoliotic patients into fully adjusted citizens, most of whom can live and work without having to rely on special measures of social welfare

SUMMARY

The treatment of structural scoliosis in the Orthopaedic Hospital of The Invalid Foundation in Helsinki during the period 1947 to 1962 is reviewed on the basis of 197 cases of spinal fusion Of these patients, 86 had idiopathic scoliosis, 99 had paralytic scoliosis secondary to poliomyelitis, and 12 were miscellaneous cases

Good correction of the deformity was achieved with the Milwaukee brace when well fitted The turnbuckle plaster cast of Risser was used for correction from 1947 to 1954 in 42 cases, but this often increased the angle of both secondary curves which was one of the motives for the adoption of the Milwaukee brace of Blount and Schmidt in 1954 Since then, the brace has been used altogether for 155 patients

The majority of the patients underwent operation between the ages of 12 and 15 years It seemed wise to postpone the time of surgical intervention, but the development of the iliac apophyses and the vertebral growth had to be closely watched The skeletal age of the patient was found to be an important factor in the planning of treatment

The operative technique improved year by year with increasing experience Three general types of fusion were employed by about 20 different surgeons First the original Hibbs fusion with articular facets fusion was used in 23 cases Secondly, in 24 cases, the method of fusion was similar to this but did not involve destruction of the articular facets Thirdly, since 1955—1956, the fusion was done by the Cobb method,

in 96 patients with the addition of bone bank bone, in 40 patients with autogenous bone and in 14 patients with both together The mean duration of the follow up period was over 4 years and for 57 patients over 6 years

Autogenous bone was far superior to homogenous bone bank bone as grafting material (see Tables 10 aud 12) Thus the results of treatment from 1947 to 1954 were poor when compared with the results achieved since 1959 and by present day treatment In idiopathic scoliosis, autogenous bone alone or together with bank bone was used as a graft in 24 patients and only 2 had pseudarthroses but 16 out of the 50 patients grafted with bank bone had pseudarthroses (see Tables 13—15) In paralytic scoliosis there were 14 cases with pseudarthroses out of 39 patients grafted with bank bone but only 5 out of 26 patients grafted with autogenous bone had pseudarthroses (see Tables 16—18)

Pseudarthroses in the fusion area proved one of the main reasons for the loss of correction after spinal fusion Thus in 46 out of 68 patients with a major loss of correction pseudarthroses were responsible for the loss (Table 11) Altogether, 57 (29 per cent) out of 197 operated cases had pseudarthroses causing symptoms

Good results were obtained in 63 cases out of 197 These patients had an average net correction of 23 per cent which corresponded to the good cosmetic result achieved In 19 (48 per cent) out of 40 patients treated with autogenous bone as supplementary graft a good result was gained Comparable results were obtained only in 25 (26 per cent) out of the 96 patients fused with the addition of bank bone

Present Method of Treatment

The severity of the deformity determines the onset of treatment with the Milwaukee brace irrespective of the patient s age A sufficient correction is achieved with the brace and with adequate training the patient learns to wear it on all occasions even at school

The degree of the deformity together with the patient s skeletal age determine the time of surgical intervention If the deforming curvature attains an angle of 40° to 50 surgery is undertaken, providing that the patient s skeletal age is over 12 years Boys are operated on about one year later than girls In idiopathic scoliosis the entire primary curve is fused In paralytic scoliosis the fusion is extended one vertebra beyond the primary curvature in both directions, the patient s balance permitting

Balance of the patient is an important consideration in determining the length of the fusion area

The operation is carried out by means of the Cobb modification of spinal fusion Only fresh tibial or iliac autogenous bone is used for grafting The extension of the Milwaukee brace involving the final correction is carried out during the 10 days following the operation The patient is kept in bed for 4 months postoperatively

The brace will be worn until the fusion is solid, and, if indicated, until the vertebral growth is completed In general, the use of the brace is gradually discontinued some 9 months after surgery

Before the patient leaves hospital 4 months after the operation, the search for pseudarthroses is begun Renewed roentgenography at the end of the brace wearing period usually reveals possible pseudarthroses If these have been found to cause loss of correction, surgical repair is indicated

The patients are submitted to follow up examinations until the growth of the spine is completed All patients with scoliosis aged 16 are, if indicated, given a full trade school course free of charge Most of them can thus learn to live and work without having to rely on special measures of social welfare

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ACTA ORTHOPAEDICA SCANDINAVICA
Supplementum 68

From the Orthopedic clinic Lund Sweden. Head G Wiberg

Shape of the intercondylar groove normally and in recurrent dislocation of patella

A clinical and x ray anatomical investigation

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EJNAR MUNKSGAARD COPENHAGEN 1964

Translator W F Salisbury
Statistical advisor R Ericsson FK

Printed in Sweden
LUND 1964
BERLINGSKA BOKTRYCKERIET

Contents

Introduction

Lorsqu on recherche dans les auteurs anciens ou modernes l'origine des doctrines asse généralement admises aujourd'hui sur les luxations de la rotule on est surpris de trouver entre eux un tel désaccord et une telle disette de faits avec une telle abondance d'opinions

(Malgaigne 1836)

Recurrent dislocation of the patella refers in this work to only those instances where on at least two occasions the patella has temporarily left its normal place on the ventral side of the femur between the condyles and for a longer or shorter time has become displaced on to or over the lateral femur condyle The dislocation will have been directly observable by the patient or others or it will from the anamnesis undoubtedly appear that it has been a question of a patellar dislocation (the release mechanism the sudden insufficiency of the extensor mechanism of the knee hemarthrosis tenderness over the medial surface of the joint x ray changes medially etc)

It is a relatively rare condition Despite this many works have been written on the subject discussing mainly the surgical treatment and it is remarkable that a condition so relatively rare as dislocation of the patella should have given rise to over 100 different methods of operation However most of them are modifications or combinations of about ten basic procedures

Regarding the causes of patellar dislocation one has been more reserved although several anatomical changes in the skeleton and the extensor mechanism have been described by some authors as cause of patellar dislocation by others as result of patellar dislocation genu valgum patella alta under developed vastus medialis changed femur torsion etc

Nearly all authors who have investigated the subject are also of the opinion that the size and formation of the lateral femur condyle might be changed in patients suffering from recurrent dislocation of the patella

The patella glides by flexion extension of the knee in a sulcus formed by the continuation of fossa intercondyloidea on the ventral side of the

femur where it is bordered by the medial and the lateral femur condyle respectively

A clear connection has been stated to exist between the size of the lateral femur condyle and the occurrence of the dislocation of the patella

Normally the lateral condyle is higher than the medial it reaches further ventrally when the patient stands it rises higher than the medial over the bottom of the sulcus and thereby prevents the patella from becoming displaced laterally

At the dislocation of the patella this lateral condyle is said to be lower than usual under developed flattened , not so high as usual approximates the medial condyle in height etc whereby it might be easier for the patella to become displaced laterally

I have been unable to discover any investigation (satisfactory in this respect) of the normal anatomy the normal size and form of the two femur condyles and consequently no investigation that shows whether and in what manner the normal anatomical conditions have been changed in patients with recurrent dislocation of the patella

The purpose of the present investigation was

1 Under standardized conditions to investigate by x rays a number of femoro patella joints in healthy persons and to obtain objective measurable expressions of the formation and size of the osseous parts of the femur condyles
2 Under the same standardized conditions to investigate patients who have or have had recurrent dislocation of the patella in order to see whether any characteristic anatomical deviations from the normal *can be found*
3 *By dividing the patient material according to different principles* (male female traumatic nontraumatic etc) to see whether these possible deviations are more or less expressed in different groups and thus contribute towards characterizing these groups

Definitions, Abbreviations, Symbols, Tables Statistical methods

A Definitions

Dysplastic changes (of the femur) the height of the lateral condyle (possibly also the medial) above the bottom of the intercondylar groove is lower than usual (where applicable this means lower than the mean of the normal material) and/or the sulcus angle L+M is larger than usual (where applicable this means larger than the mean of the normal material)

(Femoral) dysplasia is used synonymously with the above

Illusory dysplasia created by increased outwards rotation or torsion of the condyle section (see p 48)

Flexion—extension in the knee the initial position with extended knee=0°

Recurrent dislocation of the patella the patella has on at least two occasions momentarily left its usual place in the intercondylar groove and for a longer or shorter time been displaced on to or over the lateral condyle

Dislocation and luxation are used synonymously

Q angle the angle with its apex at the patella formed between ligamentum patellae and the extension of the quadriceps resultant distally Fig 7 B p 31

B Abbreviations, Symbols, Tables

LC and MC approximate expressions for the extension of the lateral and the medial condyle ventro dorsally (see p 71)

l m l_t m_t d LC and MC are expressed in mm } see fig next page and
C_p C_t L M and L+M are expressed in degrees } text pp 68—69

The figures in the tables within parentheses after dx and sin give the number of knees or of patients belonging to each column

The figures within parentheses after the column numbers of the tables indicate where they occur the numbers of the columns that lie as basis for the column involved

Column numbers 1 and 2 which in *all tables of measured results correspond to the normal values* of the right and the left side have from considerations of space been omitted in some tables but are given on next page

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3 By dividing the patient material according to different principles male female traumatic nontraumatic etc) to see whether these possible deviations are more or less expressed in different groups and thus contribute towards characterizing these groups

C. Statistical methods

Statistical calculations of mean errors and dispersion were made according to current methods (Dixon & Massey 1951).

When different groups of patients were compared with one another, and the difference between the means of the groups of I. m., C_p, I. and L+M (see Symbols) was calculated, the difference was tested two-sidedly.

The difference is said to be statistically highly significant (***) when it is 3.29 times its mean error (= 1 ‰ level), statistically significant (**) when it is 2.58 times its mean error (= 1 % level), and statistically probable (*) when it is 1.96 times its mean error (= 5 % level).

When comparing the normal material with different patient groups, the test for I. m. L. and L+M (not C_p) was performed one-sidedly and the significance limits were 3.09 (1 ‰ level), 2.33 (1 % level), and 1.65 (5 % level).

If the difference between two means is less than either of the mean errors of the means or less than 1.5 times the mean error of the normal material, no significant difference was considered to exist and the mean error of the difference was not calculated.

If in small groups (n<25) significant differences were obtained with ordinary mean error calculations, the mean error of the difference was also calculated with the aid of the greatest dispersion and the t-test was made. Where deviations from the first calculated significance emerge, this is advised in a footnote to the table or in the text.

CHAPTER I

Historical review

Thestrup Andersen (1955) states that when one delves into the literature concerning the dislocation of the patella one is first impressed by the colossal amount of casuistic information which on the basis of one or two cases describes the etiology the symptoms and the treatment without advancing anything new This I wish to endorse unreservedly In the following will be given only a summarized report of certain trends of the literature concerning patellar dislocation as well as reports of the more important works Where this has been considered suitable a brief historic review has been given in the appropriate chapters

One finds that already Galenos (129—200) gives a description of the condition and he indicates also a method of bandaging intended to keep the patella in place

During the middle ages and up to the middle of the 19th century descriptions were given of traumatic dislocations and their repositioning The first to give a collocation of the cases so far published is Malgaigne (1836) who describes 25 cases Streubel 30 years later is able to assemble 120 cases partly his own and partly from the literature In 1921 Karl collects the cases described to date a total of 296

Up to the end of the 19th century the interest is concentrated upon the *etiology and the classification of the dislocations connected with it*

The basic classification is

1 Congenital i e caused mainly by some congenital displacement or change in the skeleton or the soft parts
2 Traumatic i e caused mainly by a direct trauma
3 Pathological i e caused mainly by some pathological change which is in turn caused by some illness or accident polio fracture rickets arthritis etc

This classification is thus based upon the etiology and is used with variations by several authors Friedländer (1901) Wiemuth (1901) Soliero (1906), Ewald (1906) Finsterer (1909) Karl (1921) Conn (1925) Cole & Williamson (1934) Hauser (1938) and Houkom (1942)

Other authors classify according to the clinical picture into acute, habitual and/or recurrent dislocations (Aldibert 1894 Luckerath 1919 Kapel 1936 and Blumensaat 1938) The different nomenclature used in German and French literature must be mentioned here By habitual dislocation the French mean one that occurs every time the knee assumes a certain position which can well be physiological This form is also called pendular dislocation or permanent dislocation

On the other hand German authors usually mean by habitual dislocation that which is defined by me in the introduction as recurrent dislocation of the patella

These main groups vary and are classified and assembled in different ways by different authors without the discussion apparently being fruitful

Around the turn of the century the interest is concentrated more upon *therapeutic questions* and chiefly on surgical therapy It is surprising that the methods of operating most usual today were already published then Roux 1888 (who moved the attachment of ligamentum patellae medially) Goldthwait 1899 and 1904 (who wholly or partly moved ligamentum patellae medially or distally) and Krogius 1904 (whose muscle fascia plastic method spread rapidly) In the same year 1904 Graser published his supracondylar inwards rotating osteotomy Heusner in 1902 described his method where he being the first to do so used one of the muscles from the back of the knee joint (m semitendinosus) in order to draw the patella medially

During the following decades the surgical technique continues to be the main theme and several operation procedures and modifications are described most of them with good primary results

Other conditions are also subjects of interest Lückerath (1919) Hohlbaum (1921) and Zanoli (1926) are of the opinion that the flattening of the lateral femur condyle mentioned by many was due to changed rotation or torsion of the femur Jaroschy (1924) and Knutsson (1941) aroused interest in *the x ray investigation of the femoro patellar joint* and the appearance of the x ray picture and Wiberg (1941) studied the same joint by x ray and by autopsy

Blumensaat published in 1938 a large work on dislocations of the

patella where he discusses thoroughly the earlier literature and reports the current view of the subject The work does not in itself present anything new but has through its thorough survey of the literature and its weight made a considerable impression upon the discussion The method he describes for deciding whether a patient has a high standing patella (patella alta) has proved valuable

Beginning in the 1930 s *larger follow up series* of patient material were published and have since been continued (Kapel 1936 Macey 1937 Wallinkoski 1942 Sjövall 1943 McCarroll & Schwarzmann 1945 Seedorff 1946 Fellander 1949 Harrison 1955 Böhi 1957 Jerre & Knutsson 1958 Heywood 1961 Karlholm 1961 Rolander 1961 Hellum 1962 Cerwenka 1962 and Nicod & Nikolakakos 1963)

Most series however are relatively small composed of a maximum of 50—55 patients and are lacking in uniformity regarding etiology classification and treatment it is therefore difficult to make comparisons In 1950 Marion & Barcat published a large work on dislocations of the patella They have by questioning colleagues in France and abroad collected 218 cases (including their own patients) to which they add 273 cases from the literature of exhaustively described luxations spontanees i e not purely traumatic cases and have thus obtained 491 cases which they analyze with respect to etiology pathologic anatomy clinic operation methods results etc This work and the discussion it gave rise to has been of great importance but its weakness was that it was not a uniformly followed up and appraised material

Thestrup Andersen in 1955 published a work on dislocation of the patella where he examined journals and pictures of 315 patients who had during 1920—1951 been treated in orthopedic wards in Denmark He thereafter personally post investigated (clinically and roentgenologically) 292 of these patients He discusses etiology x ray pictures classification therapy prognosis and heredity This is by far the largest uniformly followed up material published to date

As appears from the above Scandinavian authors have often made pioneering contributions generously acknowledged in non Scandinavian literature

CHAPTER II

The anatomy and physiology of the femoro patellar joint

The following brief description of the anatomy and physiology treats only data of importance in this investigation

Femur The femur shaft terminates distally in the two condyles the lateral and the medial Together these form the two articular surfaces against partly the tibia (facies tibialis femoris) and partly patella (facies patellaris femoris) These articular surfaces merge into each other but in about 50 per cent of the cases there can be seen a suggestion of a border linea terminalis (Fick 1911) On x ray pictures taken laterally, there is seen in about two thirds of investigated knee joints an impression in the contour of the bone at this border usually interpreted as an impression of the anterior meniscus edge in the femur condyle (Ravelli 1949 Vogler 1962)

Dorsally and dorso distally the condyles are separated by a deep non cartilage covered fossa intercondylica This passes in the ventral part of facies tibialis femoris into a deep cartilage covered sulcus which continues on the ventral side of the femur and forms a part of facies patellaris femoris Fig 2 It is there shallow but separates clearly the two condyles The patella glides in this sulcus with the ridge that divides the articular surface of the patella into two facets

The ventral half moon shaped articular surface of the femur thus is concave medio laterally and convex proximo distally It extends 2—3 cm proximally on the ventral side of the femur calculated from the joint line somewhat more on the lateral condyle than on the medial condyle The lateral condyle is wider seen from the front but if the femur shaft is considered from a vertical position the medial condyle reaches further distally Because the femur shaft of the normal standing person lies at an angle of 8°—10° to the plumb line the two condyles will be approximately level (See Fig 1)

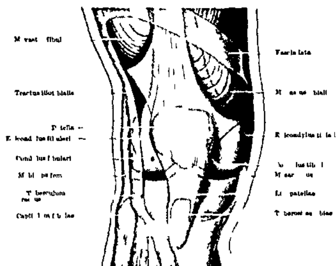


Fig 1 Skeleton and muscles round the knee joint (From Lanz & Wachsmuth Praktische Anatomie)

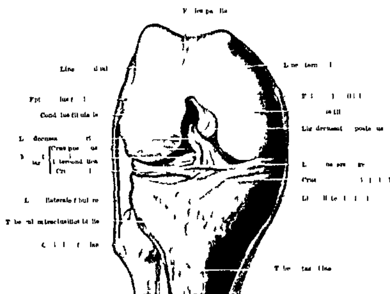


Fig 2 Knee joint without most of the soft parts flexed 90 showing the distal femur end (From Lanz & Wachsmuth Praktische Anatomie)

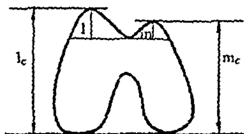


Fig 3 The distal femur end

lc = the extension of the lateral condyle ventro dorsally mc = the extension of the medial condyle ventro dorsally l = the height of the lateral condyle above the sulcus bottom m = the height of the medial condyle above the sulcus bottom

Concerning the size of the condyles in dorso ventral direction "their depth" it states in the textbooks that the lateral condyle is larger than the medial (the lateral condyle (lc) is larger than the medial condyle (mc)—Fig 3) and especially that the part of the lateral condyle which forms the lateral wall (l) in the above mentioned sulcus should be higher than the medial (m)—Fig 3) Comparative anatomy has shown that broadly speaking it is only homo that extends completely the knee and homo has also relatively the deepest sulcus (E Payr 1928) Thus for example in the gorilla facies patellaris femoris is an almost flat surface in medio lateral direction (Malkin 1932 Böhm 1935) According to Böhm this form is found in the human embryo and also in the newborn It is first at about age 12 years that we get the characteristic form with ventrally protruding condyles with a sulcus lying between Rovira & Barrios (1951) however maintain that this form appears already in the fetal stage and that from and including 3—4 fetal months the lateral condyle is dominant

The contour of the articular surfaces of the condyles is formed by the articular cartilage which varies in thickness On facies patellaris femoris it is thickest centrally about 3 4 mm and thins out towards the sides (Kopsch 1940)

Patella The patella is a flat heart shaped bone with the apex directed caudally All its sides except the dorsal are covered by different parts of the quadriceps tendon and ligamentum patellae The dorsal surface facing facies patellaris femoris is except for the apex completely covered by cartilage It is divided by a longitudinal ridge into two facets one lateral and one medial On so called axial x ray pictures of

the knee joint (see Fig. 14, p. 55) the lateral facet in normal persons is always larger than the medial (the relation lateral/medial is on average 1.4 and somewhat larger in female than in male—Brattström 1960). An unfortunate mistake has crept into Lanz & Wachsmuth's textbook of anatomy. In the text on page 241 it says that the ridge is displaced fibularwartz and on picture number 196 on the same page the same mistake occurs. This has resulted in some misunderstanding mainly in German orthopedic literature.

Both the facets and the ridge are covered with cartilage. On the ridge one finds the thickest cartilage of the body, up to 6.4 mm (Fick 1911). On an axial x-ray picture the lateral bone surface is always concave whereas the medial varies, sometimes being concave, sometimes convex and sometimes flat.

Muscles and ligaments. Of the four muscles of the quadriceps, rectus femoris and vastus intermedius pass with nearly all their fibres into a common tendon, the quadriceps tendon, to which also the largest parts of vastus tibialis and fibularis are attached. The quadriceps tendon is attached to the base of the patella except for some superficial fibres which pass by the ventral side of the patella and then pass over into ligamentum patellae. This ligament is about 2 cm wide and 3—5 cm long and extends from the point of the patella to tuberositas, where it is attached on a broad base, Fig. 1.

The distal parts of vastus fibularis, possibly combined with some fibres from rectus, do not connect with the quadriceps tendon but pass into tendon fibres, retinaculum patellae longitudinale fibulare, which immediately laterally pass the patella and attach to tuberositas tractus iliotibialis, partly intertwined with tractus iliotibialis, Fig. 4.

In the same manner retinaculum patellae longitudinale tibiale is formed by the distal parts of vastus tibialis and a few fibres from rectus and passes medially of the patella and attaches to the tibia immediately medially and above tuberositas tibiae, Fig. 5.

Under these longitudinal retinacula patellae, which are thus the continuation of muscles and consequently can extend actively, there are transverse fibres, retinacula transversalia, which issue from the fibular and tibial femur epicondyles and attach to the nearest patellar edge.

The *longitudinal retinacula* partly play an active role at the end phases of the extension of the knee (Merkel 1925, Nicoll 1943, Smillie 1946) and partly contribute by their course to retain the patella in its

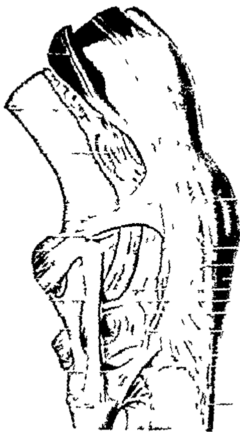


Fig 4 Fibular side of the knee joint muscles and ligaments (From Lanz & Wachsmuth Praktische Anatomie)

sulcus between the condyles during knee movements The *transverse retinacula* border the movement of the patella sideways and as reins check tendencies towards side displacements

Position of patella vertically With extended knee and contracted quadriceps usually only the caudal edge of the articular surface of the patella has contact with the most proximal part of the cartilage covered facies patellaris femoris The greater part of the patella rests against the ventral synovia covered surface of the femur and the apex is found about 2—3 cm above the tibia plateau If the quadriceps is allowed to relax but the knee still remains extended the patella by reason of the tissue turgor (and in a standing person also through the force of gravity) falls caudally somewhat medially and possibly somewhat ven

Fig. 5 Tibial side of knee joint with muscles and ligaments (From Lanz & Wachsmuth Praktische Anatomie)

trally Thus the patella will lie with its apex level with the joint line With extended knee and relaxed quadriceps the patella can be passively moved both caudally cranially and laterally medially about 1—2 cm in each direction In some persons this passive mobility is greater and in records of patients with dislocation of the patella abnormal lateral mobility of the patella or similar is often reported but these appraisals are based upon the experience of the investigator I have been unable to find exact measurements of the normal mobility

With extended knee and without movement occurring between tibia and femur, one can by alternately contracting and relaxing the quadriceps move the patella up and down This is called in German literature Patellar spiel According to Payr this Longitudinal spiel can amount to a movement of 2—4 cm

Valgus Q angle Human beings have a physiologic valgus position in the knee of 8°—10° usually some degrees more in the female because of her broader pelvis The quadriceps extends along the femur and because the tuberositas tibiae is situated in the centre line of the tibia the extensor mechanism formed by *quadriceps resultant + patella + ligamentum patellae* will form a valgus angle which immediately prior to full extension is about 175 degrees At the so called end rotation of the tibia this bone rotates outwards some degrees and thereby tuberositas tibia is moved laterally and this valgus position is increased a further few degrees *The supplement angle to this valgus angle in the extensor mechanism is in the present work called the Q angle* Fig 7 B p 31 If we proceed from the fully extended knee and then bend it in the first phase an inward rotation of the tibia in relation to the femur takes place a suspension of the so called end rotation The Q angle is thereby partly straightened

Femur torsion The femur torsion implies that a vertical plane through the transverse axis of the femur condyles on a standing person and a vertical plane through the caput collum axis do not coincide but form an angle averaging 12° with each other One usually says that the collum stands outwards torqued or anteverted in relation to the condyle plane we have a so called anteversion angle of 10°—12°

Theoretically three facts contribute to the collum axis not being in the condyle plane

a Torsion of the femur diaphysis antetorsion or retrotorsion
b The collum points forwards or backwards in relation to the proximal end of the diaphysis and the trochanter region anteversion or retroversion in a circumscribed sense or anteposition or retroposition of collum
(c Ante flexion or retroflexion of the collum itself this factor plays no role in normal conditions)

Torsion and version cannot in practice be separated from each other and most anatomists clinicians and roentgenologists treat the concepts as synonymous the anteversion angle is an expression for the femur torsion (Lanz & Wachsmuth 1938 Billing 1954) this applies also in the present work

In an isolated femur this angle is measured by lying the bone with the posterior extent of the condyles horizontal (this plane is in the following called THE POSTERIOR CONDYLE PLANE) and one measures the

angle that the collum axis forms with the horizontal plane or the posterior condyle plane (Martin 1914 Stracher 1961) Great individual variations exist and the angle between 0° and 24 cannot be regarded as pathologic One has earlier always referred this changed angle to the proximal end of the femur and spoken of an increased or reduced anteversion angle for collum femoris which has been presumed to play a large role at dislocations of the hip among other things In recent years however it has been clearly seen that a changed angle need not necessarily mean a changed torsion of solely the proximal end it can also be the distal end i e the femur condyles which through torsion have changed their position For practical reasons in order to obtain among other things a clearly defined position that makes measurements possible the posterior condyle plane has been retained as initial position

The femur torsion begins intra uterinely In a two month fetus a negative anteversion occurs i e caput points behind the posterior condyle plane In a four month fetus they are on the same level at six months a 15 positive torsion occurs i e caput points in front of the posterior condyle plane and at partus there is about 30 positive torsion (Bohm 1935) During the following years a detorsion takes place so that in the adult there is a positive torsion averaging 12 (Böhm 1935) As mentioned above these measurements are for practical reasons related to the posterior condyle plane According to Böhm (1935) and Frund (1953) among others the femur shaft actually lies in a neutral position the distal condyle end is torqued 6 inwards and the proximal collum end is torqued 6 outwards

As will be seen later some authors have attached importance to whether torquing has occurred in the distal or proximal femur end regarding recurrent dislocation of the patella

Patellas movement by flexion A normal knee joint has an active range of mobility of about 130 regarding flexion/extension Passively one can bend a further 20 to 30° i e a range of mobility of about 155° During this flexion/extension the quadriceps is so contracted that ligamentum patellae is extended and the patella lies at a fairly constant distance from tuberositas tibiae The patella usually stands at the beginning of the flexion as mentioned earlier exactly at the opening of the sulcus which is formed between the ventrally protruding parts of the condyles The patella runs in this sulcus on its longitudinal ridge

During the first 80° flexion the entire articular surface of the patella is mainly in good contact with the articular surface of the femur. This means that the pressure exercised between the patella and the femur is practically evenly distributed between the ridge and the two joint facets (Wiberg 1941). All the time however the contact with the medial facet is concentrated to a smaller surface, partly by the medial facet's being smaller, partly by its being flattened or convex or articulating with a convex articular surface of the femur. On the other hand through the Q angle (see p. 20) the largest pressure will usually be found between the lateral articular surfaces of the femur and the patella. This predominance of the pressure laterally increases at further flexion according to Wiberg's investigations.

The patella at about 90° flexion leaves facies patellaris femoris, and at maximum flexion the cranial parts of the patella, the so called bend facets, extend close to fossa intercondyloidea. Normally the ridge of the patella does not reach bottom; after a 90° flexion the entire pressure is concentrated upon the two facets, mainly upon the lateral.

In the initial position and during the first 70°—80° of the flexion one can clearly see and palpate the edges of the patella. Because the sulcus becomes not only deeper but also wider, the patella sinks in between the condyles and on a knee bent at right angles the contours are round and even and the contours of the patella can be palpated only with difficulty. In some persons the contours of the patella remain clear also at 90° flexion; the patient has pointed knees. (This condition is discussed in Chapter XII in connection with the concept patella alta.)

Other movements in the knee. At extended knee no rotation or other movement occurs between tibia and femur, but the slightest flexion results in an inwards rotation of the tibia and we quickly get an active and passive rotation capacity in the knee joint according to the following table (partly Hjortsjö 1959).

	Inwards rotation	Outwards rotation
Extended knee	0	0
At 30° bend	<5°	30°
At 60° bend	[illegible]	35°
At 90° bend	5°—10°	40

The patella has a path of between 6 and 8 cm. Through the formation of the articular surface of the femur the patella glides at the flexion

also some mm laterally which occurs continuously during the whole flexion (Wiberg 1941 de Sezé & al 1951)

Patella retention Different factors normally contribute to retaining the patella in its place in order to prevent it from dislocation

1 Quadriceps with ligamentum patellae Through muscular contraction the patella is pressed against the femur and the sulcus
2 Retinacula patellae longitudinale et transversale Articular capsule
3 Those parts of the medial and lateral condyle that protrude ventrally and form the walls of the sulcus for the patella to glide in
4 Air pressure

The nature and the function of the patella This has been much discussed Most authors are of the opinion that it is a sesamoid bone formed in the quadriceps tendon by the mechanical strains at flexion and extension (Haxton 1944 Cave & Rowe 1950 de Palma & Flynn 1958) whereas others say that the patella is formed independently of the quadriceps tendon and the function of the joint (Drachmann 1872 Bernays 1878 Kazzander 1894) Brooke (1936—37) thinks that the patella is a phylogenic rest which has no functional importance He has attempted to show by experiment with corpses that the function of the quadriceps is improved after removal of the patella

Daunegger already in 1880 and Meyer in 1883 point out that if one accepts that the patella is not a real bone but as a sesamoid bone is a part of the extensor musculature one cannot really call the condition of the bone s having left its path a luxation of the patella but a dislocation of the tendon However for practical purposes they accept the diagnosis dislocation or luxation of the patella

Concerning the function of the patella many different views have also been expressed The theory is usually advanced that through the position of the patella in the extensor mechanism the quadriceps has a more favourable angle of attack a better lever when it functions (Payr 1928 Lantz & Wachsmuth 1938 Haxton 1944—45 Cave & Rowe 1950 Furmeier 1953) Furthermore it has been maintained that the cartilage covered articular surface of the patella glides more easily against the femur and distributes the pressure against it better than a tendon would Furmeier has shown moreover that the patella has great importance for the normal functioning of the knee joint and for the

pressure not only between the extensor mechanism and the femur but also in the tibio femoral joint

Other authors have maintained that the patella lacks meaning and could be dispensed with. Some support their theories by experiments with cadavers (Brooke 1936—37, Freehafer 1962), others upon favourable results obtained at patellectomy for fractures, chondromalacia and other diseased states of the patella (*inter alia* Blumensaat 1936, Brooke 1936—37 a, Rosen 1939, Friberg 1941, McFarland 1948). Brooke's work has played a great role and has been the incentive for several orthopedists and surgeons to remove the patella at fractures.

As Scott (1949) and de Palma & Flynn (1958), among others, have pointed out, the clinical series have often a relatively short observation time. If one waits long enough, according to these authors, changes of osteo arthrosis nature appear. A closer discussion of these questions lies beyond the scope of this investigation.

Summary

A brief description of some anatomical and physiological data of importance in this investigation is given.

CHAPTER III

Recurrent dislocation of the patella

A Clinical picture

Definition

Normally the extensor mechanism glides with the patella in the sulcus on the ventral side of the femur the patella maintaining continual contact with both lateral and medial condyle At recurrent dislocation of the patella as the concept is used in the present work the patella with the extensor mechanism of the knee *temporarily* leaves on at least two occasions its normal place on the ventral side of the femur between the condyles and glides for a longer or shorter time up on to or over the lateral femur condyle At this temporary dislocation there is an acute insufficiency of the extensor mechanism and the knee usually gives way The patella sits riding on the lateral condyle or glides down on the lateral side of the femur

In patients with osteo arthrosis in the femoro patellar joint it often happens that the patella permanently loses contact with the medial femur condyle and subluxates laterally and moves at flexion/extension in this subluxated track The condition has been *developed gradually* and the patient usually has no symptoms other than those conditioned by the arthrosis deformans Subluxation or lateralization of the patella is not discussed in this work At luxation it is the medial facet that gives the pathology at subluxation it is the lateral patellar facet (Debrunner 1957)



Fig 6 A Patella in normal position in the intercondylar groove B Lateralization or chronic subluxation at osteo arthrosis in the femoro patellar joint C D Different types of patellar luxation

The patella dislocates almost always laterally. It has even been questioned whether medial dislocations occur (Thompson & Bosworth 1947 and Debrunner 1957) but several authors have given detailed descriptions of dislocations medially; therefore, this probably occurs although exceptionally (Karl 1921, Kapel 1936 and Meyer 1929).

Classification

The question of the classification of patellar dislocations has been the object of much interest and several different classifications have been proposed. Etiology and frequency of dislocation have been used as bases for classification. In these classifications, almost always two groups arise: the CONGENITAL in its wider meaning and the ACQUIRED. By the CONGENITAL is generally meant that the prerequisite conditions of the dislocation in the form of the patellar structure, sulcus structure, the femur torsion, genu valgum, poor fixation medially etc. are inborn and sooner or later, usually after a trauma insignificant for a healthy knee joint, result in a dislocation. Characteristic of these congenital dislocations might be early age at the initial dislocation, bilateral occurrence, often hereditary anamnesis, overweight in the female, dysplastic changes as seen in the x-ray picture and the almost atraumatic course. Thestrup Andersen considers that in 10 per cent of the congenital dislocations there occur also other congenital articular defects or bone defects. By congenital dislocation in restricted meaning (real congenital dislocation) is meant that the dislocation itself occurs at partus and the patella rests on the outside of the lateral condyle.

The ACQUIRED would be due either to a severe trauma (traumatic dislocations) or to changes following infection, polio, prolonged knee exudate, fracture or similar (pathologic dislocations) (Luckerath 1919).

Naturally there are isolated cases that undoubtedly belong to one or other of the groups, a factor that would have importance in selecting treatment method, but the borderline cases are too many for the classification to be satisfactory. Among other things it is most often extraordinarily difficult to decide whether a trauma has been severe or not.

In the literature dealing with dislocation of the patella so-called PERMANENT dislocations are also referred to; this to different authors often means different things.

1. The real congenital dislocation, i.e. the patella at birth is dislocated on the outside and does not reset spontaneously.

2 Later acquired dislocations which have not been reset but where the patella remained on the outside of the lateral femur condyle
3 Habitual or pendular dislocations i e the patella dislocates at a decisive movement that lies completely within the normal mobility pattern of the knee joint

It is not always clear in the works of other authors whether these permanent dislocations are also included but they are so few that they have no great importance in a large material Regarding the different meanings that German and French authors ascribe to the diagnosis habitual dislocation see p 12

Wiberg proposed in 1941 a classification into three groups dependent upon the degree of femoro patellar dysplasia as seen in the x ray picture Similar lines of thought are found in Sjövall (1943) Fellander (1949) Thestrup Andersen (1955) and Rolander (1961) but here too the borderlines between the groups are not well defined This difficulty of being able with certainty to refer a case to one or other group has caused many to hesitate about classification (Sommer 1928 Janz 1930 Payr 1934 Dickson 1936 Sjövall 1943 and Cotta 1959) Others attempt a classification according to anatomic or physiologic variant that can occur and can be suspected of causing the dislocation in order thus to be able to offer the therapy adequate in every particular instance (Moreira 1939 Herzog 1947 Lacheretz 1951 Brisard 1950 Tavernier 1950 Trevor 1957 Debrunner 1961 and Max Lange 1962)

One of my main tasks was by classifying the material into different groups according to principles used by earlier authors to show possible differences between these groups in the formation of the femur condyles and thus to contribute to characterizing these groups

Occurrence

Recurrent dislocation of the patella is a relatively rare condition This is evident from the quite small patient material presented by most authors

Thestrup Andersen has collected 315 case histories of patients all of whom have over a period of 30 years (1920—51) been treated in the Orthopedic special wards in Demnark under the diagnosis luxatio or subluxatio patellae Storck (*cit* Böhi) reports that of scarcely 50 000 patients who have visited the Orthopedic clinic at the University in

Berlin 36 had recurrent dislocation of the patella (0 73 ‰) and Schneller (cit Böhi) reports on behalf of the Orthopedic clinic at the University in Wien that 17 patients out of approximately 65 000 (0 26 ‰) had this condition Debrunner (1957) who was particularly interested in the condition has in his private clientele 1 87 per thousand

In the Orthopedic clinic in Lund during the years 1945 to 1961 (both dates inclusive) approximately 28 000 persons were treated as inpatients of whom 14 female and 20 male (fully 2 ‰) had recurrent dislocation of the patella, according to the earlier given definition

Böhi calculated that the dislocations of the patella total about one per thousand of the orthopedic clientele a figure that can be accepted

Sex

The recurrent dislocation of the patella is about twice as common in the female as in the male (Kapel 1936 Vallinkoski 1942 Sjovall 1943 Seedorf 1946 Tellander 1949 Marion & Barcat 1950 McNab 1952, and Thestrup Andersen 1955) If classification into congenital and acquired (mainly traumatic acquired) is attempted the dominance of the female appears even more clearly in the congenital group whereas in the traumatic the male dominates (Kapel 1936 Thestrup Andersen 1955 and Nikolai 1960)

Right—Left—Bilateral dislocation

In a large number of instances the condition is double sided In others, a certain dominance of left sided dislocations seems to occur From the reports of authors who classify their material into right sided and left sided dislocations I have found nothing to suggest a predominance of *right* sided dislocations In the two largest materials published (Marion & Barcat and Thestrup Andersen) the proportion of double sided is 30 per cent and 35 per cent respectively and of unilateral the left sided is 54 per cent and 53 per cent respectively Of 26 unilateral Sjovall reports 69 per cent left sided and Bohi (1957) who describes 47 cases reports 36 per cent double sided and that 62 per cent of the unilateral are on the left side

Thus approximately one third of recurrent dislocation of the patella conditions are double sided fully one third left sided and scarcely one third right sided

Age of onset

The condition usually first occurs at age 15 years in the female some what earlier in the male somewhat later That the age is later in the male can be thought due partly to later skeletal maturity and partly to traumatic injuries at increased age being more usual in the male No age however goes free

Earlier diseases

Several patients state that before the first dislocation they have had symptoms in the knee feelings of insecurity or that the knee has felt as if it would give way or similar Sometimes there occurs in the anamnesis a report of severe exudate in the knee joint either infectiously or traumatically conditioned An exudate of this nature that is permitted to remain for some time could be thought to impair and to some extent cause atrophy and lack of tone in the soft parts

In congenital dislocations there occurs in approximately 10 per cent simultaneous joint or bone defects in other parts of the body (flat foot luxatio coxae dysplasia acetabuli kyphoscoliosis spina bifida syndactylia etc) (Bauer & Göttig 1936 and Thestrup Andersen 1955)

Etiology

In the sections referring to the classification of the dislocations and to the earlier diseases trauma and chronic exudates have already been hinted at concerning the etiology of recurrent dislocation of the patella

Heredity Several authors have described families where the condition could be traced for two or three generations (*inter alios* Caswell 1865 Schou 1893 Wiemuth 1901 Bogen 1904 Hübscher 1909 Wrede 1911 Moore 1930 Bauer & Göttig 1936 and Mumford 1947)

Bauer & Göttig (1936) analyzed 18 families with congenital dislocation of the patella and expressed the opinion that a dominant hereditary tendency is involved which is not inherent in the X chromosome but has a different penetrance factor in male and female That should explain the sex difference A general over mobility in the body joints and flaccidity in the ligaments are common in patients with hereditably conditioned tendency according to Bauer & Göttig

Marion & Barcat find a family occurrence of dislocations of the patella in seven per cent of their material but they point out that if one obtains a thorough anamnesis where these problems are discussed this figure will certainly increase considerably

Thestrup Andersen (1955) who has devoted special attention to the question of heredity finds in his material of over 300 patients no less than 64 with a family occurrence of dislocation of the patella in some instances up to four generations This implies that approximately 25 per cent of what Thestrup Andersen calls congenital dislocation of the patella have a positive family anamnesis the figure for his entire material is approximately 20 per cent

Trauma Most patients report some kind of trauma at the first dislocation Purely traumatic dislocations however must be rare and presuppose a direct and severe tangential assault in medio lateral direction (e g a bumper striking the patella) From here we consider transitions via less severe *direct blows severe indirect assault (tackling during* football games jumps in athletics) to mild indirect assault (careless dancing jumping sideways and similar) By these indirect assaults it could be that the easily flexed lower leg rotates outwards with tuberositas tibiae and thereby increases the Q angle (see p 20) and the strain being too great the patella dislocates Possibly a severe and partly uncontrolled quadriceps contraction assists the dislocation Occasionally a few patients deny any trauma walked quietly along when the leg gave way

Apart from the trauma some other factor must usually be involved and several different reasons have been adduced for the patella to dislocate

Q angle The valgus angle which occurs normally in the knee joint and at extended end rotated knee also in the extensor mechanism including the patella results in the patella at the contraction of the quadriceps being forced laterally In that case it is easy to explain the dislocations of the patella by an increased valgus position Several authors have shown that patients with dislocation of the patella often have an increased Q angle (p 20) This increased valgus position can be due to different causes

1 Increased valgus position in the skeleton (Malgaigne 1836 Aldibert 1894 Trendelenburg 1900 Wiemuth 1901 Goldthwait 1904 Youdis

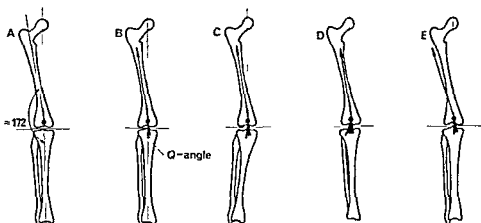


Fig 7 Different causes of increased Q angle A and B normal conditions C Q angle increased on account of increased valgus position in the skeleton D Q angle in creased because the ligamentum patellae is attached more laterally than usual (e g tibia stands outwards rotated in relation to the femur) E Q angle increased because the quadriceps resultant goes more laterally than usual (disturbed muscular balance)

1924 Friedland 1927 Stracher 1936 Blumensaat 1938 Moreira 1939 Haukom 1942 Swynghedauw & Laine 1945 Smillie 1946 Felländer 1949 Lacheretz 1951 McKeever 1951 Thestrup Andersen 1955 Le Coer 1956 von Rosen 1959 and Lange 1962) Other authors attach no particular importance to genu valgum and maintain that they have not observed anything of that nature in their patients (Borchard 1901 Finsterer 1909 Bade 1934 Kapel 1936 Blanco 1949 and Jerre & Knuts son 1958 and to a certain extent Marion & Barcat 1950) Some con sider the genu valgum secondary to the dislocations (Gocht 1918 Janz 1930 Bade 1934 and Pruvot 1950 and to a certain extent Marion & Barcat 1950) and say that it is due to the fact that at dislocated ex tensor mechanism the quadriceps serves as an abductor and pulls the lower limb into valgus position or that the Q angle is also increased by some other cause and that the quadriceps then pulls the skeletal parts into valgus position Thestrup Andersen points out in a 1959 publication that he has operated upon two patients who before the operation had genu valgum and whose legs after the operation became straight despite his having carried out only soft part operation Fig 7C

2 Tuberositas tibiae can be situated unusually laterally on the tibia

(Smillie 1946 Brisard 1950 Tavernier 1950 Francillon 1950 Rohlederer 1951 Harrison 1955 Le Coer 1956 and Bom & Motta 1960) Fig 7 D

3 The tibia with tuberositas tibiae can stand outwards rotated in relation to the femur at extended position (so called decalage according to Isermeyer 1867 Appel 1895 Zanoli 1926 Moreira 1939 Fevre 1950 and Furmeier & Breit 1952) Other authors maintain that this outwards rotation occurs when the patient has flexed 15 —20° in the knee (Streubel 1866 Wiemuth 1901 Hildebrand 1902 MacAusland & Sargent 1922) Fig 7 D

4 If the femur condyle part with the patella is thought of as being fixed the femur shaft with its muscle origins can be outwards torqued and the quadriceps resultant thus will pull laterally (Friedland 1927 and Moreira 1939) Or what is the same thing one can also imagine the shaft with the muscle origins as being fixed and the condyles with the patella torqued too much inwards This increases the Q angle but the lateral condyle is at the same time relatively more protruding which should counteract the dislocation This detail is discussed more thoroughly in Chapter IV concerning the height of the lateral condyle Fig 7 E

5 Quadriceps resultant normally pulls lengthwise in relation to the femur In an otherwise normal course of muscles and tendons it can because of pathologic weakening of the medially pulling muscles go more laterally and thus increase the Q angle and the risk of dislocation We get the same effect by increasing the lateral pulling powers Fig 7 E

This weakening medially could be due to the muscle itself in the musculature of vastus medialis being in poor condition (Gocht 1918 Bohler 1918 Blanco 1949 Brisard 1950 and McKeever 1951) The weakening can also be due to the poor condition of the connection of vastus medialis to the extensor mechanism It can have been lacerated at the first dislocation been atrophied by prolonged exudate in the knee joint been damaged at a medial parapatellar operation incision (Smillie 1946) In these circumstances the medial structures partly connected to vastus medialis such as the medial capsule and retinacula patellae longitudinale et transversale are also damaged (Tenney 1908 Whitelock 1914 Gallie 1935 Stracker 1936 Kapel 1936 Dickson 1936 Fellander 1949 and Watson Jones 1955) These structures play a considerable

role in retaining the patella in its place They can also be constitution ally flaccid in some persons (Dalla Vedova 1909 Wagner 1932 Gallie 1935 and Bauer & Göttig 1936)

Contrariwise one can by an unusually powerfully developed vastus lateralis (Duchenne 1867 von Meyer 1883 Payr 1934 and Lacheretz 1951) or by fibrous shrivelled threads in capsule and ligament on the lateral side upset the balance and give the quadriceps resultant a more lateral course (Malgaigne 1836 Guerin 1842 Daunegger 1880 Dalla Vedova 1909 Strube 1934 Ober 1935 Smillie 1946 Pruvot 1950 and Jeffreys 1963) Pruvot uses the expression torticollis du genou

Change of the Q angle at the movement of the knee Kiesselbach (1954 1956) pointed out how the position of the patella and the direction of pull in the lengthwise direction of the ligament is changed at flexion of the knee joint and what role this plays in the origin of the dislocation of the patella At extended knee and contracted quadriceps the latter pulls with a force in the patella whose resultant forms a definite angle the Q angle with the lengthwise direction of the ligament (see Fig 7 B) whose extension divides the musculature into a larger lateral part and a smaller medial part A component strives to pull the patella directly laterally and another somewhat smaller component strives to pull the patella directly medially When the knee now is bent the patella glides laterally as mentioned earlier and tuberositas tibiae turns with its liga ment attachment medially because the end rotation of the tibia is suspended and simultaneously tuberositas tibiae is carried distally be cause of the flexion The movements of both patella and tuberositas tibiae contribute towards reducing the Q angle The predominance of the laterally pulling component is reduced at approximately right angle flexion it will be equal to zero (Kiesselbach) At continued flexion the angle changes to negative we get a medially pulling component that dominates instead Because of the distal displacement of tuberositas tibiae the cranially pulling component has increased so powerfully that the medially pulling component is relatively small thus no dislocation medially ever occurs The risk of dislocation would in the opinion of Kiesselbach be greatest at extended or slightly flexed knee because

1 the patella has not yet quite glided into the sulcus and obtained sup port from the bone
2 the laterally pulling powers are greater than the medially pulling

3 the laterally pulling powers are great in relation to the cranially pulling

The therapeutic procedures which originated from Kiesselbach's reasoning will be referred to later (See Chapt IV)

Patella shape Apart from trauma and increased Q angle other factors have been quoted as causing dislocation of the patella among them the form and size of the patella Bogen (1906) points out that many patients with permanent congenital dislocation have conspicuously small patella

Jaroschy (1924) points out that the patella is thicker than normally, and says that such a patella verstandlich dislocates easily however he suggests no reasons why

Kromer (1937) states that the patella in these patients to judge from an axial x ray picture of the knee joint often has a large concave lateral facet and a small convex medial facet that almost forms a right angle with the lateral This form is later in German literature called Jager huteform although Kromer himself does not use this word He considers that this form facilitates the dislocation

Wiberg in 1941 published a work about the appearance of the femoro patellar joint in patients with dislocation of the patella There he classifies the knee joints into three groups according to the different degree of dysplasia (see Chap IV) as seen in the axial x ray picture he also considers the form of the patella These lines of thought are again partly encountered in other works (e g Sjovall 1943 Marion & Barcat 1950 da Silva 1951 Furmeier & Breit 1952 Thestrup Andersen 1955 Frund 1958 Merle D Aubigne & Ramadier 1959 and Rolander 1961)

Patella alta Deviations in vertical direction of the position of the patella have also been given as cause of dislocation of the patella Normally the patella lies at extended knee and relaxed quadriceps, with its apex level with the joint line in order at contraction of the quadriceps to be pulled 2—3 cm cranially (Patellar spiel) Here only the most caudal parts of the articular surfaces of the patella (the extensor facets) and the ridge will make contact with corresponding surfaces on the femur The bone resistance to a dislocation is consequently small in this position If ligamentum patellae is longer than normal i e more than 3—5 cm the patella will lie completely over facies patellaris femoris and be altogether without bone support laterally First when the patella by

flexion in the knee joint has been drawn caudally it runs into" the sulcus and gets this bone support A high standing patella of this nature is called patella alta vera (Murk Jansen 1930) In extended position and during the first degrees of flexion the patella in patients with patella alta might thus be more "vulnerable" be more easily dislocated especially as the quadriceps pulling laterally is according to Kiesselbach strongest in this position This high standing patella patella alta vera is considered by *inter alios* Murk Jansen (1930) Moreira (1939) Tavernier (1950) Lance (1950) Wiles (1951) McKeever (1954) Thestrup Andersen (1955) and Harrison (1955) as one of the main causes of the dislocation of the patella whereas MacAusland & Sargent (1922) Kapel (1936) Haukom (1942) McCarroll & Schwartzmann (1945) Smillie (1946) Blanco (1949) Francillon (1950) Lacheretz (1951) da Silva (1951) Fürmeier & Breit (1952) Max Lange (1962) and Debrunner (1962) only ascribe to patella alta a certain importance Marion & Barcat mention patella alta only in passing and Thompson & Bosworth (1947) directly deny the importance of patella alta

No fixed borderline between normal and pathologic position of the patella in the vertical plane exists The first to occupy himself with the question was Schulthess (1899) who described some spastics with high standing patella He pointed out that with the knee flexed at right angle or pointed angle the patella sits normally sunken between tibia and femur however in these spastics it sits as an extension of the femur

Peltesohn (1901) and Blencke (1902) have the same basis for their estimation whereas Boon Itt (1930) describes an involved method for estimating the position of the patella in the vertical plane with the aid of an x ray picture taken laterally

Blumensaat (1938) has described a method for deciding whether patella alta occurs or not This is used by among others Waberg (1941) Fürmeier & Breit (1952) and Thestrup Andersen (1955) Blumensaat s method necessitates that on an x ray picture of the knee joint taken laterally the sclerotic line formed by the cortex on the bottom of fossa intercondyloidea be extended so that this line cuts across the patella or its extension Fig 8 This line called Blumensaat s line normally meets apex patellae when the knee is flexed 30 degrees Provided the apex lies above Blumensaat s line at this flexion the diagnosis patella alta is established

Most authors fail to indicate how they determine whether patella alta



Fig 8 On an x ray picture of the normal knee flexed 30° apex patella lies on the extension of the sclerotic line formed by the bottom of fossa intercondyloidea (Blumensaat s line) u = the angle between this line and the longitudinal axis of the femur (see text)

exists Thestrup Andersen who uses Blumensaat s line diagnoses 207 of his 286 patients with dislocation of the patella as having patella alta even after allowing a margin of about 5 mm above Blumensaat s line before characterizing the condition as such (Personal communication)

Femoral dysplasia As well as different forms of increased Q angle femoro patellar dysplasia (Knutsson 1941) is the pathologic anatomical change that has been most indicated as cause of the dislocation of the patella chiefly that the lateral condyle lies lower than normal it does not offer the patella the support needed to prevent dislocation laterally

Because it was my main purpose to investigate more closely this femoral dysplasia I will report earlier investigations in this sphere as well as the present view in a special chapter (see Chapter IV) the dysplasia being mentioned here merely to complete the picture

Wiberg and Thestrup Andersen include in the femoro patellar dys

plasias also patella alta and those changes of the form of the patella mentioned earlier that often result in an incongruity in the femoro patellar joint

Where does the patella dislocate?

The patient can usually indicate the position in the knee where the dislocation occurs

Dislocation in flexion position This is undoubtedly the most usual It is related to among other things the fact that the extensor mechanism seeks the shortest course between its origin and insertion This attempt results in the patella s being pulled *laterally* because of the earlier mentioned valgus angle (Q angle) and at flexion position after dislocation also backwards

The outwards rotation capacity of the tibia as soon as the knee is flexed plays a large role Especially the first 10 —20° of the flexion is critical because the lateral pulling powers are greater than the medial pulling (Kiesselbach 1956) and the patella has not yet completely run into the sulcus especially if patella alta exists (Wiemuth 1901 Bohler 1918 MacAusland & Sargent 1922 Hoffmeister 1928 Sommer 1928 Kapel 1936 Moreira 1939 Trevor 1947 Ståhl 1950 Wiles 1951 Teal 1954 Bohr 1957 Debrunner 1961 and Max Lange 1962)

Wrede (1911) Böhler (1918) Jerre & Knutsson (1958) and Cerwenka (1962) point out that the dislocation can happen down to 90° flexion

Houkom (1942) and Lewin (1952) maintain that it is during *extension movement* that the dislocation usually occurs about 20 before full extension The essential might be the slightly flexed knee and the contracted quadriceps whether it is under flexion or extension probably plays no role

Dislocation in extension position This does not occur according to McKeever (1954) whereas v Meyer (1883) and Daunegger (1880) according to the literature say that it is the most usual form

The end rotation of the knee at full extension and the traction of the muscles in this position (Kiesselbach 1956) would favour a dislocation in extended position but at the same time the patella will in most cases lie cranially to the opening of the sulcus and cannot dislocate because it has no bone support at the sides Ligamentum patellae which then runs

in the sulcus is flexible and follows the course of the sulcus rather than dislocates Dislocation in extended position unquestionably occurs but is unusual

Course

First luxation As earlier mentioned nearly all patients refer to trauma as cause of the first dislocation When the anamnesis is examined one finds that it is only in isolated instances that a powerful direct assault on the inner side of the patella has caused the dislocation Considerably more frequent is the effect created by the condition fixed foot—slightly flexed knee—inwards rotation of the body and the thigh i e an increase of the Q angle with dislocation is a result The patient gets an acute insufficiency of the knee extensors the knee gives way and the patient usually falls The patella can sometimes spontaneously reset but often the patient himself or somebody available must render aid Sometimes the patient comes to hospital with the patella still dislocated The dislocation is very painful and afterwards the patient is often tender at the medial edge of the patella indicating injury in the soft parts there The medial structures wholly or partly are lacerated at dislocation retinacula patellae longitudinale et transversale articular capsule connection of vastus internus to the quadriceps tendon and patella (Kapel 1936 Smillie 1946 and Thestrup Andersen 1955) Several authors have stated how important it is that this acute injury in the medial structures be allowed to heal and recommend it be set in plaster for a time after dislocation (Schloffer 1906 Whitelock 1914 Gallie 1935 Kapel 1936 and Watson Jones 1955) and Thestrup Andersen (1955) recommends exploration and suture in order to prevent a recurrence One has also discussed the risk of stretching with consequent atrophy and flaccidity of the soft parts which the traumatic exudation in the knee involves

Sometimes the soft parts can at dislocation escape damage but the attachment at the medial edge of the patella is lacerated carrying with it a larger or smaller osseous fragment This gives a very characteristic x ray picture at the so called axial view (Jaroschy 1923) Stahl (1950) has pointed out that fractures of the patella can occur at dislocation under other circumstances too 1) A piece of the patella can be planed off" by the lateral condyle when the patella glides back 2) At dislocation caused by direct assault the violence can cause a compression

fracture of the patella medially 3) When the patella sits on the outside of the lateral condyle it is often the medial facet of the patella that is the contact surface and at attempts to reset we can get a compression fracture there 4) Lacerated fracture can occur on the medial edge of the patella according to earlier description

An analysis of the x ray picture can in doubtful instances determine whether the diagnosis dislocation of the patella is valid

In connection with the dislocation a hemarthrosis usually develops

The further course can develop vastly differently in different cases owing partly to the prerequisite conditions for dislocation existing primarily before the dislocation and partly on how this first dislocation *with injuries in the soft parts has been treated*

A few patients never again experience a recurrence of dislocation of the patella whereas most after a longer or shorter time get a recurrence then it usually follows a lesser violence than at the first dislocation Thus the development continues the patella dislocates more and more easily with increasingly shorter intervals until eventually it perhaps happens more than once a day if the patient fails to learn to avoid the provocative movement Usually however a patient nowadays comes under treatment before the condition has developed so far

Between the dislocations the patients are often unsure have feelings in the knee think the knee will give way do not quite trust the knee joint and this feeling of insecurity can for these often young and active persons be a severe handicap partly in certain professions and partly by preventing them from taking part in for example dancing and sports

The condition is double sided in about one third of the cases It is not unusual that because the patient is convalescent after dislocation or surgical treatment of one knee the other knee is more loaded and dislocates too On the other hand it happens that a patient with double sided dislocations gets well in both knees after a successful operation in one of them Here the mechanism is reversed the patients gets a steady leg (that operated upon) and can then take the weight off the other

Diagnosis

The diagnosis is usually easy even though the patella has been reset The patient cannot always describe directly how the patella sat on the

outside of the lateral condyle but a diagnosis can usually be obtained by means of the anamnesis with heredity release mechanism earlier episodes of the same type and the description of the actual occurrence with its acute knee insufficiency The diagnosis is confirmed afterwards partly by the clinical investigation hemarthrosis tenderness at the medial edge of the patella possible palpable defect there in the soft parts and high standing patella which is possibly hypermobile laterally In doubtful cases x ray examination can be decisive femoro patellar dysplasia of varying type and degree and possibly typical fractures of the patella (Stahl 1950)

The condition however is relatively unusual and not all doctors are familiar with it

In some instances the diagnosis can be difficult for the specialist too

B *Therapy*

Spontaneous cures Conservative treatment

Some cases cure spontaneously after several dislocations (Mumford 1947 McNab 1952 Böhi 1957 and Debrunner 1957) By spontaneous cure is meant those instances where the dislocations cease to recur The patients usually have other knee troubles It is here often either a question of the patient having learnt to avoid the dislocation provoking movement or of degenerative changes in the form of osteo arthrosis or indurations which give less mobility and thereby increased stability

However Heywood who in 1961 published a material concerning 106 knees in 92 patients who had dislocated the patella has obtained a good and lasting effect through quadriceps training in 15 patients all these patients were young

In some instances where surgical treatment is for one reason or an other unsuitable or where the patient refuses it one tries conservative therapy which according to Thestrup Andersen is suitably divided in to active and passive treatment The active consists mainly in training the quadriceps The passive treatment consists of different bandaging of which the usual elastic bandage or knee bandage has often a good effect More or less complicated orthopedic bandages have also been constructed and are used beneficially by some patients (e g Haudek s bandage)

Among the conservative methods might also be mentioned that de

scribed by Hugh Owen Thomas in 1892 by every week banging the atrophic lateral condyle in two patients he stimulated it to "growth and thus cured the dislocations (cit Cole & Williamson 1934)

Treatment by operation

The operation I performed was largely of an experimental nature and was done in the following manner (Robertson 1912)

The treatment of recurrent dislocation of the patella has been a fertile field for the growth and development of the surgical ingenuity (Haukom 1942)

These two quotations describe the situation rather well More than *100 different operations have been mentioned Cotta (1959) reports 137* of which however most are larger or smaller modifications of about ten basic procedures or combinations of these An account of these operations is outside the scope of this work those interested are referred to the work of Blumensaat (1938) In Chapter IV those surgical treatments related to the shape of the femur condyles mainly the apparent or real dysplasia of the lateral condyle are more closely reported

Some of the most usual operation methods used in Scandinavia are depicted in Fig 9 and Fig 12 Some operation methods are also men

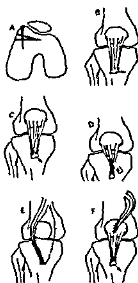


Fig 9 Some of the most notable operation methods used for recurrent dislocation of the patella See also Fig 12 p 51 A Raising the lateral condyle according to Albee (1915) B Removal of the attachment of ligamentum patellae medially according to Roux (1888) C Removal of the attachment of ligamentum patellae medially distally according to *inter alios* Hubscher (1909) D Removal of the lateral part of the attachment of ligamentum patellae medially the so called Goldthwait II (1904) E Combination operation according to Krogius (1904) F Combination operation according to McCarroll & Schwartzmann (1945) using m semitendinosus

tioned there that are directly associated with the femoral dysplasia (see Chap IV)

The patients who form the basis for my investigations come from the Orthopedic clinics in Lund Malmö Kristianstad Hälsingborg and Copenhagen They are mainly operated on according to the following

Lund and Kristianstad modified muscle fascia plastic according to Krogius (see Fig 9) The modification consists partly of the ligamentum patellae being routinely transferred medially distally and partly of the distal shank of the lambeau being severed for operation technical reasons

Malmo and Hälsingborg *removal of the ligament attachment medially distally* Often called Hauser s operation but described in principle by Goldthwait (1904) and Hubscher (1909)

Copenhagen ligament removal according to Goldthwait II (see Fig 9) or combination operation according to McCarroll & Schwartzmann (see Fig 9)

C *Prognosis*

The course of a recurrent dislocation of the patella can go in different ways Some heal spontaneously others dislocate very seldom giving no trouble in the meantime whereas some suffer increasingly frequent dislocations and moreover experience trouble during the intervals

Every dislocation is more or less damaging to the knee joint the cartilage is damaged we get a hemarthrosis or hydrops or we can get fractures of the patella As end result of the recurrent dislocations we often get osteo arthrosis in the femoro patella joint as well as in the tibio femoral joint The dysplasia in the form of patella alta contributes also to this as do different changes in the form of the femur and the patella that usually occur in this condition In trying to avoid this early operation is recommended Possible damage to the soft parts is treated surgically at the first dislocation (Schloffer 1906 Whitelock 1914 Kapel 1936 Watson Jones 1955 and Thestrup Andersen 1955) and at possible recurrence the treatment demanded by the particular case is used

More than 100 different operation methods have been suggested which is usually a sure sign that the ideal operation is not yet to hand When one reads the works of different authors however one is im

pressed by the fact that good primary reports accompany the large *number of operation methods used on so few patients* It is for several reasons very difficult (from the literature) to form an opinion of the prognosis at surgical treatment

1 Most published investigations contain only few cases
2 Different authors use different classifications and there is no uniform nomenclature
3 *The observation time is usually quite short it is the primary results* of the operations that are appraised The long term prognosis with regard to osteo arthrosis function in the femoro patellar joint dis location recurrence etc has not attracted the same interest

Greater follow up series with observation periods exceeding a whole year are rather unusual Where they exist the optimism that marks the primary operation reports seems lamentably lacking Marion & Barcat have surveyed the literature and find that in the published series with *an observation period exceeding one year* (chiefly Marzani 1930 Mac Ausland & Sargent 1922 Horwitz 1937 Haukom 1942 Vallinkoski 1942 and McCarroll & Schwartzmann 1945 and in Scandinavian literature Kapel 1936 Sjovall 1943 Seedorf 1946 and Fellander 1949) the re *currence frequency is nearly 20 per cent*

Marion & Barcat s own material—they have an observation period exceeding three years—reveals that almost every third case suffers a recurrence of dislocation Because of the nomenclature confusion it is difficult to analyze in detail but several authors point out that the *greater the role the initial trauma has played in the first dislocation* the better is the prognosis and the greater the anatomical changes that occur in for instance the form of femoro patellar dysplasia the greater the risk of recurrence (*inter alios* Fellander 1949 Jerre & Knutsson 1958 and Rolander 1961)

Thestrup Andersen also reaches similar conclusions in his large fol low up series

It is not only the recurrent dislocations however that are of interest Many patients complain of other troubles pains immobility of the *joint instability and swelling* Osteo arthrosis in the femoro patellar joint is usually seen on the x ray picture in such cases

The writings of the authors mentioned above suggest that approxi mately one third of the surgically treated patients suffer a recurrence of the dislocation one third get other knee troubles and the remainder

are in the main trouble free Patients with femoro patellar dysplasia are considered to have worse prognosis than others

Böcker stated already in 1904 that every case must be analyzed so that the surgical treatment can be individualized this principle is emphasized by other authors (Wagner 1932 Herzog 1947, Tavernier 1950, Debrunner 1961, and Max Lange 1962)

D Summary

A survey of the clinical picture the treatment and the prognosis of recurrent dislocation of the patella is given

CHAPTER IV

The femoral dysplasia

A *Definition*

Knutsson (1941) is the first to use the concept femoro patellar dysplasia although the changes underlying the concept have been known and described for a long time By it Knutsson means that the characteristic osseous profile of the femoro patellar joint on a so called axial x ray picture i e with the beam directed in the patella s longitudinal axis is changed in a typical manner The lateral condyle which normally rises markedly above the bottom of the intercondylar groove and is higher than the medial condyle is smoothed down and approaches the medial in height In pronounced instances the height of the two condyles above the groove is reduced facies patellaris femoris becomes cylindrical i e the sulcus is so very shallow that it is scarcely visible (see Fig 10)

This bony appearance on the x ray film resembles that found in embryos and newborns and is partly also found in e g the gorilla (Bohm 1935)

Parallel with this *femoral* dysplasia is also a dysplasia of the *patella* This can be noted in the characteristic change in the appearance of the patella as seen on an axial picture the marked ridge which runs in the longitudinal direction of the patella somewhat tibially to the middle is displaced more and more tibially and is at the same time usually less marked so that in the most dysplastic cases we have an almost flat surface on the patella which articulates against an almost flat or rather a cylindrical surface on the femur This femoro patellar dysplasia at dislocations of the patella has been studied by among others Wiberg (1941) who used the degree of dysplasia to classify the dislocation of the patella

Fellinder (1949) and Thestrup Andersen (1955) use the concept fem oro patellar dysplasia the latter includes also patella alta in this

As mentioned above the changes lying behind the concept femoro



Fig 10 Different degrees of femoro patellar dysplasia as it appears on an axial x ray picture according to Knutsson A/D Normal B/E moderate dysplasia C/F pronounced dysplasia

patellar dysplasia were known long before the concept was created The low lateral condyle was the main object of much interest before x ray examinations were possible and it has been thought by several authors (see p 48) to be the principal reason for dislocation of the patella

Those authors who earlier used the concept dysplasia about the femoro patellar joint based their appraisements upon an estimation of the shape of the intercondylar groove on axial x ray pictures taken by various methods As will be demonstrated more closely in Chapter V these methods are impaired by several elements of uncertainty with the result that the above mentioned appraisements also are uncertain

In this chapter I use the concept femoral dysplasia to mean that the lateral condyle does not seem to shoot so far ventrally as it does normally in relation to the sulcus bottom For reasons I give on pp 55—58 no more exact definition can be given here When some authors mention also a lower medial condyle and other changes this is referred to specially

B *History*

Already in 1802 i e before the start of the roentgen epoch Richerand describes three instances of dislocation of the patella and points out that in all of them the lateral condyle was lower and he sees this as the reason for the dislocations

Isermeier (1867) lays *the foundation for one of the many subjects* of controversy which marked the discussion of the dislocations of the patella in that he certainly acknowledges the dysplasia but considers it secondary to the dislocations This view is shared by many authors chiefly in the early literature Bade (1903) considers that mainly at traumatic dislocations the lateral condyle is in the beginning more or less normal compared with the medial condyle (possibly the entire distal femur end is more gracile than usual) but is rubbed down by the *repeated dislocations* Bohler (1918) *expresses* the opinion that it is a pressure atrophy of the lateral condyle and Friedland (1925) too believes that the dysplasia is secondary

The arguments against the dysplasia s being secondary were proffered already in 1901 by Wiemuth 1) it cannot be a rubbing down *or pressure atrophy because the cartilage on the lateral condyle is in* tact 2) some patients with very frequent dislocations have completely normal lateral condyles 3) and at the real congenital (existing at partus) dislocations dysplasia is often present In addition Malkin (1932) among others has pointed out that only man walks with ex*tended knees and with the thereupon resulting end rotation of the* tibia in relation to the femur This end rotation increases the Q angle (see p 20) and increases the pressure of the patella against the lateral condyle and as long as this pressure lies within physiologic limits it stimulates the growth of the lateral condyle Consequently man alone has a lateral condyle higher than the medial under normal circumstances Sheep and cattle on the contrary have the medial higher in apes the two condyles are similar in height At certain forms of dislocation for example the real congenital this physiologic stimulation might not occur and we thus have secondarily a low lateral condyle (Malkin *1932)*

The discussion of the degree and type of the femoral dysplasia was put upon a more solid basis after it became possible to reproduce roentgenologically the femoro patellar joint on so called axial pictures (Jaroschy 1923 1924 and Knutsson 1941) (see Fig 13)





D

E





F

Fig 10 Different degrees of femoro patellar dysplasia as it appears on an axial x ray picture according to Knutsson A/D Normal B/E moderate dysplasia C/F pronounced dysplasia

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plus the insufficient balance in the musculature which he considers the increased anteversion brings about results in a forced outwards rotation of the femur at flexion in hip and knee joint Through this forced outwards rotation of the femur the pull on the patella by the quadriceps will be more lateral and at the same time oblique so that it will turn the patella out of the sulcus by raising the medial edge of the patella This lateral pull would successively stretch the medial reins and cause the lateral reins to shrink all contributing to favour the origin of a dislocation By means of the outwards rotation of the femur the lateral condyle becomes relatively lower and provides less resistance to the dislocation If now the soft parts have gradually stretched on the medial side and shrunk on the lateral side then according to Hohlbaum it only needs a powerful but completely physiological quadriceps contraction for the patella to be turned out of its position and to dislocate

Hohlbaum s work is difficult to grasp and speculative It is not based upon convincing investigations

Zanoli (1926) on the other hand maintains that the dislocation is due to an outwards rotation of the tibia and an inwards rotation of the distal femur end Whether by that last expression he means an inwards torsion of the condyle section (which increases the Q angle providing the patella follows in its groove) is not altogether clear but his opinions appear to have been accepted by several Italian authors (Zurria 1934 Masseroni 1952 Vinditti 1954 and Vinditti & Forcella 1958)

Those authors who would see the femoral dysplasia as illusory wholly due to changed torsion or rotation of the femur ignore what has sometimes earlier been pointed out that *not only has the lateral condyle been lowered but the entire articular surface* has been smoothed down both on the patella and on the femur thus producing that fetal form indicated by Bohm There is no doubt however that several of those instances that clinically and roentgenologically have been described as dysplastic *could* be due to a changed femur torsion or rotation

If the lateral condyle is poorly developed ventro dorsally as well as cranio caudally there is a low lateral wall in the sulcus as well as an increased valgus angle in the knee Both these changes have been considered to be dislocation producing

C Therapeutic views of the femoral dysplasia

The femoral dysplasia with its low lateral condyle has been blamed for dislocations of the patella It has been felt desirable to strengthen in some way this lateral condyle to make it higher or somehow to build up the poor support Different methods reflecting the earlier mentioned views of dysplasia have been tried

Pollard (1891) Kirmission (1898) and Drew (1908) described isolated instances where they found a shallow sulcus at the operation and by chiselling out tried to give the patella a suitable groove to glide in Murphy (1914) complements the method by introducing fat and fascia tissue in order to prevent femoro patellar ankylosis These methods have only historical interest

Trendelenburg (1900) strikes out in another direction in that he makes an osteotomy in the lateral condyle breaks it up , and then fills the defect with ivory

Luxembourg (1914) mentions a procedure which he ascribes to his chief Bardenheuer He makes a 1 1/2 cm deep cleft in the lateral condyle close to the anterior edge of facies patellaris and puts in a 3 1/2 cm long fibula splinter The description of the operation is very brief and there is no mention of whether a raising of the articular surface was attempted (as in the case of Trendelenburg and later Albee) or whether he wanted to build up an osseous dislocation barrier in the form of a bone lip but apparently the effect was both

Bone barriers of this type (without raising facies patellaris) are recommended by Samson (1928) Estor (1933) Stracher (1936) and Saegesser (1949) where suitable

Albee (1915) describes a method whereby on the outside of the lateral condyle he chisels in under its ventral articular surface (facies patellaris) lifts it ventrally fills the defect with a wedge of bone from the tibia and secures it into position with a bone spike in the edge of the articular surface (see Fig 9 A p 41)

Albee s operation has been widespread and several authors recommend it although at the same time there is a warning concerning technical difficulties involved in the procedure (Wagner 1932 Cole & Williamsson 1934 Morwa 1934 Swynghedauw & Laine 1945 Steindler 1946 Tavernier 1950 Lewin 1952 Trevor 1957 and Debrunner 1957)

Strong criticism however has also been voiced Francillon (1950) maintains that Albee s operation is mechanically completely wrong

On the axial picture it looks attractive but if the condyle is seen laterally there must be one or two stages in the articular surface which has been raised like a plateau Lacheretz (1951) has similar misgivings about Albee s operation and personally I agree with Francillon and Lacheretz

A variation of this osteotomy on the lateral condyle is described by Brisard (1950) who in patients with patella alta—where the patella after the knee has been flexed 10 still lacks support from the lateral condyle—chisels an incision *above* the lateral condyle caudally lifts the corticalis forwards and puts a transplant in the pocket Brisard himself calls his operation Albee superior

Graser (1904) chooses another method when he wishes to raise the lateral condyle he makes a supracondylar osteotomy on the femur and rotates the condyle section *inwards* (see Fig 12 B) This method attracted several followers but as with Albee s operation a warning was voiced principally concerning the difficulties of mobilizing the knee after the long period of inactivity (Finsterer 1909 Schantz 1910 Drehmann 1921 Max Lange 1951 and Rutt 1959) According to these authors the method ought to be reserved for difficult cases an attitude adopted by Graser himself

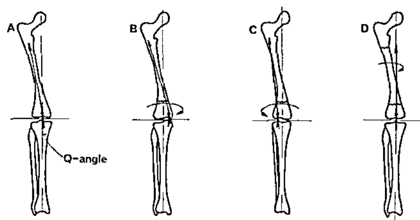


Fig 12 The effect on the pull of m quadriceps and on the Q angle (see text) of different proposed rotation osteotomies A Normal Q angle B Supracondylar *inwards* rotation osteotomy according to Graser (1904) Q angle increases C Supracondylar *outwards* rotation osteotomy according to Furmeier (1953) and Kiesselbach (1956) Q angle reduces D Rotation osteotomy according to Vinditti & Forcella (1958) Q angle reduces

As earlier mentioned the opinion was expressed that the dislocation might be due to an increased inwards torsion of the distal femur end including the patella (or an inwards rotation of the femur and the patella in relation to the tibia) This results in an increased Q angle and an increased danger of dislocation Graser's *inwards* rotation osteotomy would thus be completely illogical and ought instead to be replaced by an *outwards* rotation osteotomy to decrease the Q angle (see Fig 12 C) (*Lacheretz 1951 Furmeier 1953 and Kiesselbach 1956*)

Max Lange (1951) recommends in severe cases osteotomy according to Graser but from the text it appears that he means outwards rotation osteotomy

The Italians Vinditti & Forcella (1958) go a step further they recommend supracondylar plus subtrochanteric femur osteotomy and thereafter inwards rotation of the femur shaft freed in this manner including about 4/5 of the origin of the quadriceps musculature (see Fig 12 D) In this way they accomplish a reduction of the Q angle The method does not appear to have attracted any followers

Femur osteotomy is a big operation that demands prolonged after treatment *I have not encountered any instance of recurrent dislocation* of the patella that justified my suggesting an operation of this nature to the patient

D *Summary*

Almost all authors who have concerned themselves with the subject agree that the ventral part of the lateral condyle is low in patients with recurrent dislocation of the patella

Whether this is due to a *real substantial* decrease in the height of the lateral condyle above the bottom of the intercondylar groove or to changed torsion and/or rotation conditions producing an illusory lowering is disputed This question could not be resolved with the prevailing *roentgen examination technique*

Because of this the theoretical fundament of therapy directed against dysplasia has become unclear and is disputed The proposed operations have had only limited scope they are technically difficult and call for long convalescence also the enthusiastic advocates wish to reserve the operation for special occasions

An attempt to determine the extent of a possible dysplasia and whether this dysplasia is real or only illusory was one of the main purposes of the present work

CHAPTER V

Roentgen examination of the distal femur end and the femoro patellar joint by so called axial picture

A *Earlier methods*

The ordinary frontal and lateral pictures of the knee joint can give valuable information to a trained roentgenologist concerning the form of the femoro patellar joint (see *inter alios* Ravelli 1949 and Vogler 1961) However for the problems I discuss here the so called axial picture of the femoro patellar joint is of supreme importance The patella usually dislocates (see Chapt III) when the knee is slightly flexed i e when the patella lies against facies patellaris femoris and it is this part of the articular surface that is of interest in this connection The first to describe a method of obtaining such an axial picture is Settegast (1921) In Grashey s roentgen atlas he is named the originator of the examination method wherein the patient lies prone with maximum flexed knee (see Fig 13 A) This method is still in frequent use It demands good mobility in the knees and gives a picture of fossa intercondyloidea and of facies tibialis femoris but not of the sulcus and of facies patellaris femoris Jaroschy and Altschul in 1923 together describe a method wherein the patient lies supine with the knee flexed about 60° and the cassette along the upper surface of the thigh and the tube at the foot end (Fig 13 B) This gives a better picture of facies patellaris femoris The method named after Jaroschy has been modified so that the patient lies prone but retains the flexion in the knee (see Fig 13 C) The methods of Jaroschy and Settegast have been used by several authors and seem with various modifications still to be the most used (Kromer 1937 Moreira 1939 Schinz *et al* 1952 Harms 1953 Levitin & Colloff 1956 Files 1959 Clark 1962 and Cerwenka 1962)

The methods have definite disadvantages If one wishes to have the roentgen beams at right angles to the cassette it requires a flexion of more than 90° in the knee which is often clinically impossible to accomplish and which moreover gives a picture of the patella in fossa intercondyloidea and not in the sulcus

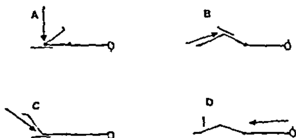


Fig 13 The roentgen beam at different methods of taking so called axial picture of the femoro patellar joint. A according to Settegast B according to Jaroschy C according to modified Jaroschy D according to Knutsson

However if one attempts by a *small* flexion in the knee to obtain a picture with the patella still in the sulcus the beam has a too large divergence from the rigth angled reception angle to the cassette which lies along the upper surface of the thigh A distorted picture results

Knutsson (1941) describes a new method the patient lies supine and flexes the knee about 40° The tube is at the head of the patient and the cassette is at about right angles to the x ray table immediately below the middle of the lower leg The central beam is not quite parallel with the x ray table it is lowered 1—5° distally (see Fig 13 D) By this method one obtains a right angled reception angle to the film and the patella is taken longitudinally This results in a good picture of the sulcus with the patella Normally the picture is taken with 40—50° flexion but if the patient has mobility difficulties usable pictures can be got with only 30° flexion The angle between the femur and the central beam is about 25° with a flexion in the knee of 40° and an angle between the central beam and the x ray table of 0—5°

This axial picture obtained by Knutsson s method has been used by among others Wiberg (1941) de Sèze & al (1951) McNab (1952) Fründ (1958) Andersen Baumgartl & Gremmel (1961) Rohlederer (1962) and to some extent Thestrup Andersen the latter however also uses Jaroschy s technique with the patients in prone position Kohler & Zimmer (1956) recommend Knutsson s method The patient material of Marion & Barcat (1950) is irregularly investigated but mostly according to Jaroschy

Fürmeier (1953 1961) has modified Knutsson s technique so that with retained flexion in the knee of about 40° he raises the heels and instead has the beam direction parallel with the table He therefore also has the angle between the femur and the central beam about 25° Fürmeier has the patient keep the legs together with the feet and knees touching and exposes both knees at the same time



Fig 14 A and B axial x ray pictures according to Knutsson The same knee but different investigation occasions Because of increased outwards rotation B seems more dysplastic than A C and D ordinary photograph of skeletal preparation to show the importance of rotation for the ventral contour of the condyle section

With Knutsson s investigation technique good information is obtained concerning the axial appearance and form of the patella and also of the femur articular surface However it gives uncertain information regarding the height of the condyles and this is one of the most important matters at the dislocation of the patella

A person lying in the position described by Knutsson can for example happen to make a very slight *outwards rotation* in the hip joint —a matter of less than 5°—and thereby *lower* the lateral condyle in relation to the medial condyle and this can produce on the x ray picture the impression of a dysplastic joint (Fig 14) Or a patient with a low lateral condyle can by a slight *inwards rotation* in the hip joint (unnoticeable by the roentgen staff) happen to get a completely *normal appearance* of the femoro patellar joint

3 No clearly defined reference point or reference line is found in the appraisal of the condyle heights
4 The methods give no idea of whether a faulty position of rotation or torsion has played a role

B *The author's investigation technique*

Because I wished to study the femoral part of the femoro patellar joint the current investigation technique was not satisfactory as can be judged from the foregoing

I must demand of the method

1 That the femur is retained in the same position at each examination irrespective of whether the same individual or another is examined or that one can disregard possible deviations from this position or can correct them when measuring on the x ray pictures
2 That the possible deviation of the cassette from the horizontal plane does not play any role
3 That one has clearly defined reference points or reference lines that permit exact measurements
4 That the measure gives an idea of the position in space of the entire distal femur end and not only that of facies patellaris femoris

Apart from a uniform positioning of the patient at the examination one should preferably photograph the anterior and the posterior condyle area at the same time on the same film with the horizontal line projected on to it This would mean that for example one photographed in the femur's longitudinal axis with the cassette at the knee (see Fig 16 A) Because this is at present impracticable I have instead on the same occasion taken two pictures with the knees flexed at about 90° *one of the ventral condyle area and the other of the dorsal* The pictures were taken with a roentgen tube at the foot end and the cassettes at the popliteal spaces and on the front surface of the thighs (see Fig 16 B)

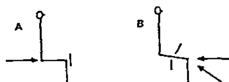


Fig 16 A The roentgen beam at the theoretically ideal investigation method of the distal femur end B The roentgen beam at the author's investigation method

Examination arrangements and x-ray procedure

The picture of the posterior area was taken with horizontal beam direction. Because of the soft parts of the thighs it was not possible to have the same beam direction in the two pictures. It was found that 30° was the smallest angle between the two central beams that would enable me with confidence to get these pictures routinely. If the angle was made smaller I ran the risk that the tangent ray through the ventral condyle area did not meet the upper cassette, especially if the flesh and the musculature were powerfully developed and thus raised the cassette (see Fig. 17).

The method requires either two roentgen tubes or one tube that can easily be swung round an axis and thus be used for both pictures. Most

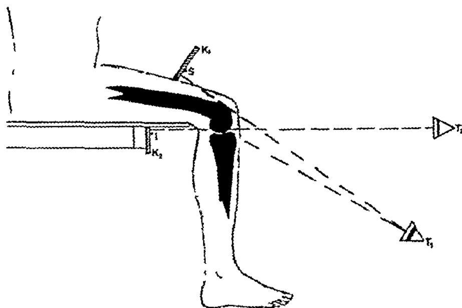


Fig. 17. The course of the beam and the patient's position at the author's investigation method.

T_1 = the roentgen tube 30° below the horizontal plane for the ventral picture
T_2 = the roentgen tube in the horizontal plane for the dorsal picture
K_1 and K_2 = casettes
S = Superior steel wire (see text)
I = Inferior steel wire (see text)

tomographs meet this latter requirement, and because I had access to a tomograph of the type Danatom A this was used

The x ray examination is carried out as follows (Fig 18 19 20) on the foot end of the x ray table a wooden lamella is fixed This protrudes about 10 cm from the narrow end of the table and is covered on the surface with lead impregnated rubber In the lamella immediately at the narrow end of the table there is a slit that runs parallel with the edge of the table Through this slit an envelope packed non screen x ray film is set The film thus lies firmly against the end of the table (see Fig 18)

On the underside of the lamella at the front edge of the slit and parallel with the slit is stretched and secured a fine steel wire I_1—I_2 (*I*nferior) See Fig 17 and 19 The lamella is so adjusted that the wire runs horizontally This is checked with a water level each time the lamella is set on the table The steel wire thus produces a horizontal line on each picture of the dorsal condyle section

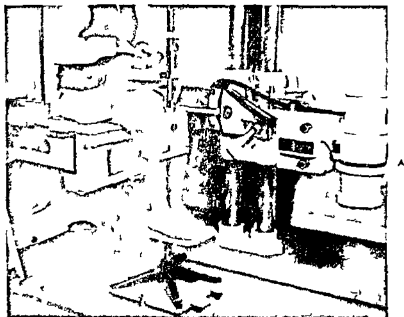
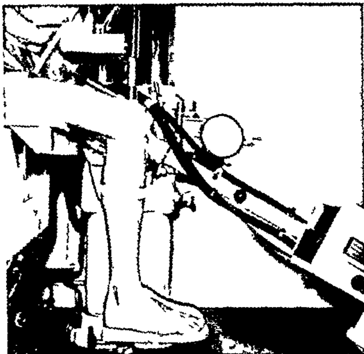
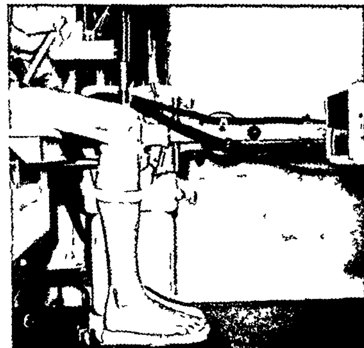


Fig 18 The patient in position for examination For details see text A General view The lead impregnated curtain not in photograph B The roentgen tube in the lower position for photographing the ventral part of the condyle section C The roentgen tube in the upper position for photographing the dorsal part of the condyle section





c

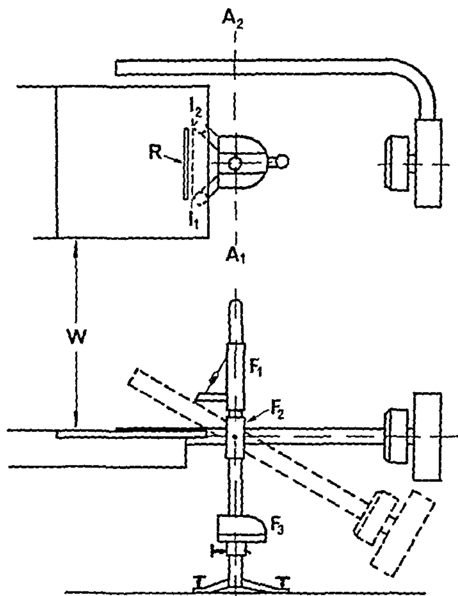


Fig 19 Schematic drawing of the investigation arrangements seen from above and from the side The top picture does not include the upper casette support F_1 with the steel wire S — S

$A_1 - A_2$ = Pendulum axis of the Danatom also = the axis through the *joint markers* (see text)

$I_1 - I$ = Inferior steel wire to indicate the horizontal line on the dorsal x ray picture

W = Wooden plate secured to the roentgen table

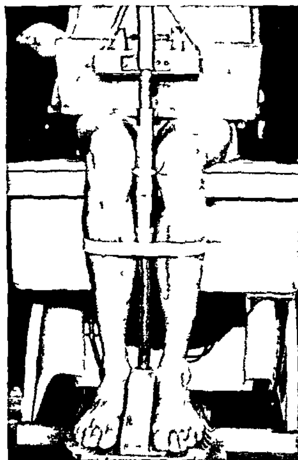
R = Slit in the wooden plate for roentgen film enclosed in an envelope

F_1 = Upper casette support (with $S - S_1$ superior steel wire not in picture)

F_2 = Knee support with "joint markers" (see text)

F = Footplate—can be raised or lowered

Fig 20 I Photograph of investigation arrangements seen from the roentgen tube



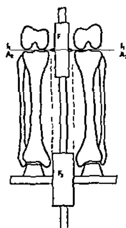


Fig 20 II Schematic drawing of the above For symbols see Fig 19

On the floor below the foot end of the table in the extension of the mid line is set a firm stand with a vertical steel pillar whose centre is 25 5 cm from the slit with the steel wire This pillar carries three adjustable supports on above the other (F F F Fig 18—20) intended to support feet knees and ventral cassette

The lowest support (F_3) consists of a plate upon which the patient at the examination places his feet one on each side of a dividing barrier through a hole in which runs the steel pillar The plate can be raised or lowered by means of a cog wheel and can be locked in position

This figure was found empirically different distances were tested but with this distance I almost always got appraisable pictures of both the ventral and the dorsal condyle section

The middle support (F_2) is intended for the knees. On each side a metal point protrudes: the joint markers. These joint markers are a full cm long and about 1 cm wide at the base and are intended to rest against the vertex of the medial joint line on each knee (see Fig. 20).

The axis A_1—A_2 through these joint markers is the central factor at the examination and serves to relate the two pictures. The whole stand and its middle support (F_2) is so placed and adjusted that A_1—A_2 is *partly* parallel with the steel wire I_1—I_2 and level with it and will therefore coincide with I_1—I_2 on the lower dorsal picture taken with horizontal beam direction and *partly* identical with the pendelum axis of the Danatom. The central beam from the roentgen tube goes through this axis irrespective of the position of the tube.

The distance between the points of the joint markers is equal to the thickness of the dividing barrier of the footplate, i.e. 5 cm (see Fig. 20).

The distance between the axis A_1—A_2 and the steel wire I_1—I_2 is 25.5 cm.

The uppermost support (F_3) carries a wooden block which holds the cassette. The front (facing the patient) is inclined 30° forwards upwards in relation to the vertical plane (see Fig. 17). Inlaid in the lower edge of the front is a steel wire S_1—S_2 (Superior). With screws and a built in water level the cassette support can be so placed that the steel wire S_1—S_2 is horizontal and 20.4 cm (see Fig. 23 I and p. 71) above the horizontal plane through the steel wire I_1—I_2 and 25.5 cm from the axis A_1—A_2 (see Fig. 23). This steel wire S_1—S_2 thus produces a horizontal line on each picture of the ventral condyle section.

A water level and an indicator light in the roentgen tube enable us to check that the stand pillar with the three supports is vertical and stands in the extension of the mid line of the table. The roentgen tube is then swung down to its lower position 30° below the horizontal plane and secured. The whole of the lower half of the roentgen beam is screened off by a lead covered brass plate which glides on two runners in front of the diaphragm being set in its lower position (see Fig. 18).

The enveloped film is set into the slit in the lamella so that its top edge is level with the surface of the lamella. The patient is placed appropriately unclothed on the lamella with one leg on each side of

From an investigation technical standpoint the height above the horizontal plane could be chosen within quite wide limits, e.g. between 19 and 22 cm. The height 20.4 cm was chosen because this figure simplifies the calculations of LC and MC (see p. 71).

the stand and the feet on the footplate The medial malleoli are held close to the dividing barrier on the footplate The medial joint line in the knee joint is palpated and by the patient s moving forwards or backwards on the lamella and by regulating the height of the foot plate an attempt is made to get the two joint markers on the middle support to rest against the vertex of the medial joint line of each knee When the position is satisfactory an elastic band is stretched round the patient s calves which helps him without any undue muscular effort to retain this position throughout the examination

A 15×40 cm cassette is placed lengthwise across the patient s thighs inclined against the above described cassette holder it thus lies 30° to the vertical plane At the examination the patient is told to press the cassette *lightly* against the soft parts of the thighs He is told the essentials of the examination and that *two* pictures are to be taken that the tube will be moved between the takings but that he must keep still and lightly press the cassette against the soft parts and not try to help in any other manner One checks by palpation that the patient s heels are planted firmly upon the footplate the patient must confirm this and also that he sits comfortably and is not tensed With an indicator light it is checked that the knee contours stand out against the upper cassette The patient is not allowed to press the cassette so hard into the soft parts that it changes the angle of inclination. The upper film is then exposed which thus pictures *the ventral area of both knees*

Then as quickly as possible adjustments are made for exposing the lower film

1 By swinging up the tube to horizontal beam direction (thus the central beam through the axis A—A of the joint markers and through the steel wire I—I on the underside of the lamella)
2 By raising the lead covered brass plate which is automatically lodged in the upper position so that the *upper* half of the roentgen beam is screened off (see Fig 18)

After that the lower film is exposed and pictures *the dorsal condyle area of both knees*

During the entire procedure the patient sits quiet without however holding his breath and he need not be troubled by cassette changes etc When the method was finally shaped and had come into use it took with very small variations an average of 10 seconds from beginning the first exposure to concluding the second Having in mind the rela

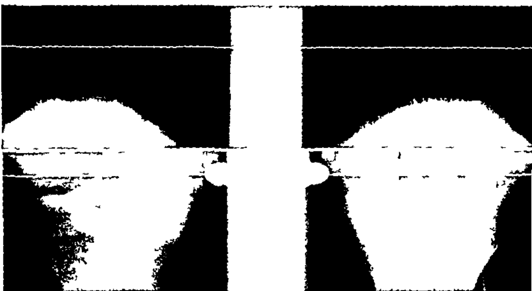


Fig 21 A The two x ray pictures the upper = the ventral section of *both* knees the lower = the dorsal section of *both* knees

tively comfortable conditions for the patient I believe that no change in position have occurred during this short interval and the pictures can for my purpose be regarded as having been taken simultaneously

In this way two practically simultaneous pictures are obtained of *both* knees one picture of the ventral area of the condyle sections of the knees and the other the dorsal On the two pictures, a horizontal line is projected (the steel wires I_1—I and S_1—S) Fig 21

In this position the longitudinal axis of the femur forms an angle of about 9° to the horizontal plane (maximum 11° minimum 5°) according to what I have found on x ray side view pictures taken of 20 males and females with varying *flesh* and musculature The x ray beam then forms an angle of about 25° with the longitudinal axis of the femur i e about the same as Knutsson s method

With the chosen measurements and placings one thus obtains appraisable pictures in most cases at the first exposure On the ventral upper picture the ventral contour of the condyles always lies below the projection of the steel wire S_1—S_2 usually 3—5 cm below it whereas on the lower dorsal picture, the condyles usually lie immediately below the projection of the steel wire I_1—I In very short and fat or muscular patients there is the risk of the upper cassette s being raised so high

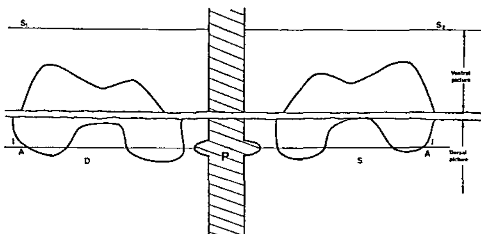


Fig 21 B Schematic drawing of the same things

S_1—S = Superior steel wire horizontal line on the ventral picture
I —I = Inferior steel wire horizontal on the dorsal picture
A —A = Pendulum axis of the Danatom also = the axis through the two joint markers
P = Metal stand with the two joint markers

by the soft parts that the ventral condyle area will not at the first attempt be included in the picture However by raising the footplate a few cm (though not enough to risk losing the condyles in the dorsal picture which are also re taken in the new position) and at the same time asking the patient to press down the cassette a little more into the soft parts of the thighs than at the previous exposure acceptable pictures are almost always obtained Of the pictures of about 500 subjects that I have x rayed in this final position only two failed

Measurements and calculations on the roentgenograms

On the two x ray pictures obtained in the described manner certain measurements and calculations were made

I *The upper ventral picture* (Fig 22)

The horizontal line S —S (*Superior*) which always lies above the ventral contour of the condyles is parallel displaced down towards the sulcus and thus three points are obtained the highest point of the

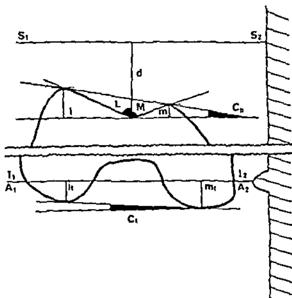


Fig 22 Drawing (one knee only) that shows the distances and angles which have been measured (x ray pictures show both knees) See text for symbols

lateral condyle the highest point of the medial condyle and the lowest point in the sulcus *Through* as well as *to* the last mentioned point four lines are drawn a horizontal line a vertical line and a line to each highest point on the lateral and the medial condyle Finally the points on the lateral and the medial condyle are connected by a line called *the ventral or the patellar condyle line, which forms an angle C_p (patellar) to the horizontal line through the sulcus bottom* Because the lateral condyle usually is higher than the medial this angle is open laterally In those isolated cases where the medial condyle is higher, we get instead a medially open angle which is thus given a minus sign

The height of the lateral condyle above the horizontal line through the sulcus bottom is called *the lateral condyle height and is indicated by l*

The height of the medial condyle above the same horizontal line is called *the medial condyle height and is indicated by m*

The perpendicular distance between S_1—S_2 and the bottom of the sulcus is indicated by *d*

The angle between the vertical line and the line from the sulcus bottom to the top of the lateral condyle is called *the lateral sulcus angle and is indicated by L*

The angle between the vertical line and the line from the sulcus

bottom to the top of the medial condyle is called *the medial sulcus angle and is indicated by M*

L+M (the angle between the lines from the sulcus bottom to the tops of the lateral and medial condyle) is called *the sulcus angle*

II *The lower dorsal picture* (Fig 22)

The horizontal indicator line I—I is parallel displaced until it touches the posterior area of one condyle and that of the other Thus we have two points which represent the most dorsally situated parts of the condyles *These two points are connected by a line the dorsal or the tibial condyle line This forms an angle C_t with that horizontal line which touches the most dorsally lying condyle* This angle is usually open laterally (as a sign that the medial condyle dips deeper than the lateral condyle) and is given a plus sign The investigation method ensures that this posterior area lies close to the indicator line I_1—I The distances between this line and the two points that represent the most dorsally lying section of each ondyle are *indicated by l and m_t* (tibially) respectively and are given a plus sign if they lie below I—I and a minus sign if they lie above this line

III *Calculations common to both pictures*

The extension of the condyles ventro dorsally

A cassette is placed upon the x ray table and leaned against the upper cassette support without any patient sitting on the table (Fig 23 I) The roentgen tube is in the lower position for taking a ventral upper *picture The central beam goes through A in Fig 23 I According to* earlier definitions (Fig 21)

A—A = the axis through the joint markers = the pendelum axis of the Danatom

I—I = the inferior indicator line

S—S = the superior indicator line

The projection of A—A on the upper cassette in Fig 23 I is called B—B

A B I and S = points in a common sagittal plane on the lines A_1—A_1 B—B I—I and S—S

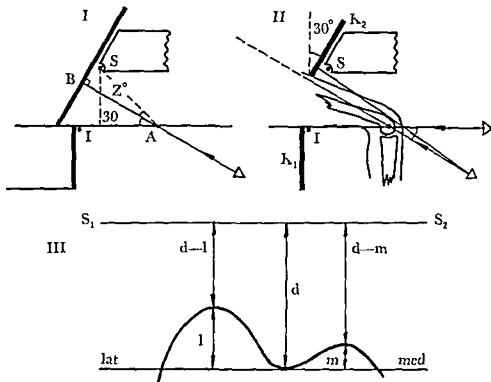


Fig 23 Drawing to show the roentgen beam and how LC and MC were calculated See text

I Roentgen beam without test subject The cntral beam through A strikes the upper casette in B

II Roentgen beam with test subject The upper casette is raised and is no longer within the central beam

III Calculation of LC and MC See text

According to the experimental conditions the distance S—A is 255 mm and the distance between S and the distance I—A is 204 mm

From Fig 23 I we get $\sin(30+Z) = \frac{204}{255}$

$Z = 23\ 1$

$\sin 23\ 1 = \frac{B-S}{255}$ $\qquad$ $B-S = 100$ mm

Thus we know that the projection of the axis A_1—A_1 is always 100 mm below the line S_1—S even though this projection is omitted from the picture

When a patient sits on the table the cassette will be raised so much by the soft parts of the thighs as to put it out of range of the central beam through A—A, and we get no projection B—B of the joint markers (Fig 23 II) The picture of the ventral contours of the condyles always lies below S—S and by measuring the distance between the sulcus bottom and S—S (d on Fig 23 III) on the picture we can because we know that B—S is 100 mm calculate the distance between the sulcus bottom and B_r—B This is 100—d The distance between the top of the lateral condyle and B—B is 100—d+l and the corresponding distance from the medial condyle is 100—d+m Fig 23 III

The investigation method was so arranged that the joint markers would mark the medial joint line and the points on the condyles that are most dorsal in this position Table 2 shows that between 3 and 9 mm of the condyles lie below the joint markers somewhat more for the medial condyle than for the lateral It shows also that these figures are about the same whether it concerns the condyles of the normal material or those of patients with dislocations of the patella

Mainly uniform and similar sized parts of the posterior condyle area lie below A—A I therefore make an approximation by adding the distance l_t to that part of the lateral condyle which on the ventral picture lies above A—A and which was calculated by the formula 100—d+l The distance thus obtained I let express the ventro dorsal extension of the condyle i e its depth

The same calculation is made for the medial condyle

The calculated distance 100—d+l+l_t is called LC and is an approximate expression for the extension of the lateral condyle ventro dorsally and the distance 100—d+m+m_t is called MC and is an approximate expression for the extension of the medial condyle ventro dorsally The size of the approximation is to some extent unknown and LC and MC must be appraised with the utmost care

Roentgen technical information

All patients were investigated with a Danatom type A with standard measure

The length of the arm of the pendulum from focus to pendular axis is 87 cm Focus 1 2×1 2 For the ventral upper picture a cassette with a reinforcement screen is used For the dorsal lower picture whereon the condyles are projected very close to the edge of the film envelope

packed non screen film is used Here the film reaches to the edge of the envelope whereas on an ordinary cassette about 1 cm of the edge is lost and this may sometimes exclude the condyles from the picture
The upper picture is exposed with 80 mAs at 80 kV the lower with 125 mAs at 100 kV

In order to reduce the radiation as much as possible the following precautions were observed

1 The surface of the wooden lamella was covered with 3 mm thick lead impregnated rubber
2 In front of the opening of the tube a lead covered brass plate was set This screened off the lower half of the beam when the upper picture was taken and *vice versa* Fig 18
3 The shutters were adjusted carefully
4 A lead impregnated curtain hung in front of the patient and rested upon his thighs Fig 20

The dosage loading of gonads and thorax was tested at the Radio physic Institution by BD—11 chambers with a sensitivity area 10—300 mR the dosage received was negligible

Errors at the roentgenography

There are some sources of error at this roentgenography
The adjustment of the height and the angle of the tube is relatively coarse and a displacement of some mm up or down as well as a difference of a few degrees at different examinations could not be avoided The indicator light however has facilitated the symmetric uniform adjustment

The largest source of error can supposedly be caused by the subjects not taking precisely the same position in the apparatus

I have tried to reduce this source of error by undertaking all examinations personally I have helped the patients to place themselves correctly have palpated the medial joint line and have ensured that normal routine was followed

With the indicated technique I have tried to examine all the patients with the femur in the same position every time I have found it practically impossible to set the femur in the correct position and to fix it *directly* there By fixing the lower leg with the medial tibial condyle immediately above the medial malleolus and by having the knee flexed

about 90 I have tried to fix the femur *indirectly* in the same position at each examination of the patient These two structures (medial malleolus and medial tibial condyle) are easily palpable even in rather adipose persons

The femur however can with this flexion at almost right angles in the knee joint rotate a few degrees on its longitudinal axis even with fixed lower leg if one firmly fixes the legs in this position and asks the patient to try to move the feet directly laterally the patient will tense the inwards rotators of the femur and a gap of a few degrees will result laterally in the knee joint *vice versa* if one asks him to press the feet together he will tense the outwards rotators and a gap will result medially (Brattstrom 1962) In the relaxed position of the patient at the examination one can ignore this forced movement and consider that the femur in this respect occupies *the same position every time the same patient is examined*

Different patients can in this position have the femur in different rotation positions owing partly to individual differences in the incline of the articular surface of the tibia in relation to the vertical line through the tibia and partly to the different development of the dorsal area of the femur condyles (see Fig 24)

The medial joint line is usually easy to palpate approximately but it is more difficult always to place the medial joint line and the vertex exactly against the joint markers and variations occur The joint line sometimes would sit somewhat above or more frequently somewhat below the joint markers which did not always come against the vertex but somewhat before or behind it Also the angle that the longitudinal



Fig 24 Different possibilities for obtaining reduced height of the lateral sulcus wall (called l in this work) in knee flexed at approximate right angles See also Fig 26 p 106 A Normal B *The ventro dorsal extension of the lateral condyle is less be*cause the ventral part of it is low Femoral dysplasia C The dorsal part of the lateral condyle is low therefore the femur stands outwards rotated Illusory dysplasia D The articulated surface of the tibia stands obliquely therefore the femur stands outwards rotated Illusory dysplasia

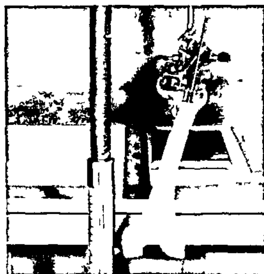


Fig 2a Preparation from the osteologic collection mounted for investigation of method errors See text

axis of the femur formed to the table could vary somewhat on average I found 9° (5°—11° see p 66)

In order to determine the extent that reasonable variations in these respects (i e the different body constitution of the patients and their various positions at the examination) played a role the following experiments were carried out

I x ray examined first three femora from the osteologic collection They were fixed firmly on a stand in the investigation position approximating that occupied by the femur in the patient Graded changes in the position of the preparation could be achieved (see Fig 2a)

The usual measurements were made on the roentgenograms

1 The femur was mounted with the joint markers against the calculated joint line vertex and the shaft forming 10° to the table The stand with the preparations was moved 1 2 and 3 cm backwards and ventral pictures were taken in each position Thereafter the stand was replaced in its initial position and then moved 1 2 and 3 cm forwards i e towards the roentgen tube The condyle section was thus moved a total distance of 6 cm whereas the cassette and the tube remained constantly in the same place No dorsal picture was taken On the ventral picture the usual measurements were made The results for all three bones lie within the margin of error(see Table 1)

The variation distance 6 cm is considerably greater than the one we need to take into account in practice

2 The femur was mounted with the distal end about 2 cm lower than the position aimed at when examining the patient The marker was thus about 2 cm ventrally to the joint line whereas the collum end was found at normal height above the table From this initial position the distal end was raised ½ cm at a time until the point was about 1 cm dorsally to the joint line (with the collum end constantly retained in position) A roentgenogram was taken in each position

The results for all three bones lie within the margin of error (see Table 1)

3 The distal femur end was kept fixed in position but the collum end was raised so that the femur shaft from the initial position with an angle of 5° to the table via 8°, 11° and 14° was finally x rayed at an angle of 16° to the table The results for all three bones lie within the margin of error

4 The femur was *mounted in the position aimed at when examining* the patient and a ventral picture was taken Then the collum end was moved 3 cm laterally and 3 cm medially and pictures were taken in *these extreme positions which thus lay 6 cm apart The distal femur* end remained undisturbed The investigation is intended to show the extent to which the pelvis width plays a role at the patient examination

No difference could be measured

One can get an idea about the effect that the different rotation position of the femur can have upon the measured values by the following experiments

5 *A ventral x ray picture can be turned round* a sagittal axis through the sulcus bottom This corresponds to a rotation change of the femur It appeared that a turn of 2° gave a result in the measurements If for example such an artificial outwards rotation of 2° was made it resulted in a decrease of L an increase of m and a decrease of C_p L increases and M decreases and the sum L+M is unchanged at rotations that were kept within ± 5°

In order to determine to what extent *small* rotation movements played a role for the measured results the following experiment was made

6 Twenty patients were x ray examined in the usual manner placed upon the examination table with their *feet on the footplate* A 3 mm thick piece of cardboard was then put between the medial malleolus

TABLE 1

The number of deviating measured results obtained at two different measurements of the same picture (col 1 and 2) and at the measurement of two different pictures of the same knee (col 3)

For column 1 1 week between the measurements column 2 the assistants were unaware of each other s results column 3 a minimum of 1 week between the two x ray examinations and the measurements

In no instance were the deviations more than 1 unit (degree or mm) and negative and positive deviations occurred to the same extent

Col	1	2	3[1]
	100 knees x rayed once measured twice by the author	100 knees x rayed once measured once by each of 2 assistants	100[1] knees x rayed twice each measured once by the author
l	19	28	30
m	14	7	18
C_p	24	25	40
C_t	14	17	28
L+M	33	39	30

[1] 50 knees were x rayed and measured the figures then doubled

and the right side of the dividing wall on the footplate and a 6 mm thick piece in the same place on the left side and new x ray pictures were taken The feet were thus separated and this resulted in an inwards rotation of the femora All pictures were measured by me three times with a minimum interval of one week between each measurement and the mean was recorded With a distance between the medial tibia condyle and the medial malleolus of 35—40 cm the change of rotation is less than 1°

It appeared that already a change of rotation of the femur of this magnitude resulted in changes in the measured results Placing the cardboard pieces gave as mentioned an inwards rotation of the femur and we could expect an increase of l decrease of m increase of C_p and C_t decrease of L and increase of M

On the right side where the 3 mm piece was placed no tendency was noticed in the figures but on the left side an increase of l in 6 of the 20 patients and a decrease of m in 3 patients were measured C_p and C_t had increased equally in 6 patients L had increased in 5 patients and M decreased so that L+M was unchanged

7 In order further to illustrate the source of error that can lie in the patients being differently positioned at the examinations I made the following experiments 50 knees were photographed twice an interval of at least 24 hours intervened between the exposures Then ordinary measurements were made and the difference between the first x ray and the second was recorded The results appear in Table 1 In no instance was there recorded a difference greater than one unit The table shows that the number of differences are as expected somewhat greater at this examination than those noted when I measured twice on the same picture

Errors in measuring the roentgenograms and in calculations

Both the normal material and the patient material were measured three times once each by two assistants who were the same throughout the investigation and once by me None of us knew the results of the others measurements In no case was there any difference larger than one unit (mm or degree) between the three measurements and at least two measurements agreed This majority result was considered valid The measurements were given in whole mm or degrees A report of the difference between the measurements by the two assistants of 100 right knees in the normal male material is given in Table 1 as well as the differences obtained between two measurements made by me on the same pictures at an interval of one month With increased experience differences in the results of our measurements of the same pictures occurred less often

The difficulty was to say precisely where the point of intersection on the parallel horizontal line occurred on the softly rounded contours

Furthermore we measure the *bone* contour and do not positively know how the cartilage helps to form the sulcus

The given distances were measured on the pictures in mm but it must be observed that 1 mm on the picture does not correspond to 1 mm on the bone This has no importance for my discussion of the results

Because the magnitude is about the same I have preferred to retain the designation mm instead of introducing a special unit for these measurements[1]

[1] The picture enlargement is about 1 3/1 at the distances used

Those approximations made at the calculations of LC and MC are reported on p 71

What do these measurements signify?

The measured distances and angles together give an idea of the shape of the intercondylar groove and of the anatomical structure of the distal femur end

l and m indicate how high above the horizontal line through the sulcus bottom the lateral condyle as well as the medial reaches when the lower leg of the patient is held vertically and the x rays form an angle of approximately 20°—25° to the femur shaft C_p gives an idea of the difference in this height between the lateral and the medial condyle C_α gives an idea of the rotation and the torsion conditions of the distal femur end

L M and L+M give an idea of how steeply the walls of the sulcus rise and together with l and m give a picture of the shape of the intercondylar groove

LC and MC give an approximate idea of the extension dorso ventrally of the lateral condyle as well as the medial significant enough to allow comparisons between patients and normals investigated by the same method

L and M were during the calculations treated partly by themselves and partly together (L+M) *The last expression, L+M, gave the best charateristic of the sulcus form and was, moreover independent of the rotation and the torsion conditions within reasonable limits*

C *Summary*

The usual roentgen methods for examining the intercondylar groove are not suitable for measuring exactly the groove and possible changes in its shape The present author has devised a method whereby the distal femur end and the groove are x ray examined under standardized conditions

On the x ray pictures certain distances and angles were measured in order to get expressions of the shape of the intercondylar groove See Definitions

CHAPTER VI

Normal material

A Composition

The normal material at the x ray examination is composed of 100 females and 100 males all of whom I myself examined The female group consisted of staff at the Orthopedic clinic and patients treated there for complaints not involving the lower extremities The male group consisted also of staff at the Orthopedic clinic (porters and staff in the bandage workshop) and patients with complaints not involving the lower extremities and also about 40 university students The average age of the female material is 30 2 years (18—48 years) and of the male 31 0 years (19—52 years) All the investigated persons denied any knee troubles apart from milder traumatic episodes No family anamnesis has been recorded They gave their age and height and when they were placed upon the examination table I established that the legs were symmetrical and that no atrophies existed These persons had to undergo no detailed clinical examination Only the two special pictures of the distal femur end were taken The pictures were measured three times by me and by two assistants (once each) in the earlier described manner (see Chap V)

The average age of the normal material was somewhat lower than that of the patient material

	Females	Males
Normal material	30 2	31 0
Patient material	34 6	32 2

In order to get an idea whether this age difference plays any role I have taken those females in the normal material whose age exceeded 30 years a total of 40 the average being 38 9 years and treated their measurement results independently They did not differ from the other normal material

The average height of the female normal material was 166 6 cm the male, 177 2 cm In order to get an idea whether the body length had any influence upon the measurement results, I treated in a separate group the 28 male normal cases that exceeded 180 cm It showed no tendency to differ from the other normal material

B *Results of measurements*

The results of the measurements of the normal material are shown in Table 2 and 3

1 *The posterior condyle plane is not horizontal* This is shown in Table 2 and 3

When anthropologists measure the torsion of the femur they put the leg on a horizontal surface with the posterior sides of the two condyles as supports and then relate all angles to this posterior condyle plane (Martin 1914) Clinically when one wishes to measure the femur s so called anteversion angle which is an expression for this torsion this is done roentgenologically (see p 20) Most of the methods used in Scandinavia are based on the principle that the patient is allowed to lie on an examination table with the lower legs hanging over the edge of the table the central beam directed vertically By rotating the femur inwards it is seen on the fluoroscopic screen or in serial films when the femoral neck is projected to its maximum length on the screen or the film i e when the longitudinal axis of the femoral neck is horizontal The lower leg hanging over the edge of the table serves as an indicator

TABLE 2

Mean values of the distances m_t and l_t and $m_t - l_t$ (see Fig 22) of 100 normal females and 100 normal males

	♀ dx	♀ sin	♂ dx	♂ sin
m_t	5 75	29	9 92	9 32
l_t	2 80	3 90	6 22	7 50
$m_t - l_t$	2 83	1 39	3 70	1 82

the number of degrees it deviates from the vertical is taken as a measure of the degree of anteversion

This examination method is based on the assumption that the posterior plane of the condyles in the position in question is horizontal

It proved however that in the normal material the dorsal condyle line i e the line through the most dorsally lying points on the respective condyles was not usually horizontal With that horizontal line which is a tangent to the most dorsally lying condyle it forms an angle C_t which is usually open laterally as a sign of the medial condyles lying lower than the lateral in the actual examination position Fig 22 This position on the part of the femur and the tibia is the same as the roentgenologists use at anteversion measurements

This appears also from the measured distances l_t and m_t on the figure where m_t is nearly always larger and the difference $m_t—l_t$ thus is positive (see Table 2 and Fig 22)

The figures in Table 2 have not been arranged statistically because the rotation position of the distal femur end is expressed better and more direct by the angle C_t in Table 3 than by the difference $m_t—l_t$

The figures in Table 2 were reported partly in order to give the reader an idea of the size order of the measured distances and thus also an idea of the extent of the fault made when we with the aid of l_t and m_t calculate approximately LC and MC (see p 71) and partly to give a preliminary orientation of the rotation position of the femur end

Already here is also seen the difference between right and left side this will be discussed more closely later

In Table 3 there appears a detailed report of the findings at the measurements of the normal material

2 *Right and left side are not symmetrical* As appears in the table there occurs a statistically significant difference between right and left side the height of the lateral condyle (l) is less on the left side whereas the height of the medial condyle (m) is greater There has thus partly occurred a levelling between the condyles

Therefore it follows that the ratio l/m is also less and the difference l m is less on the left side

The angles also are changed C_p the ventral condyle angle is smaller on the left side and the medial sulcus angle (M) is *also smaller* whereas the lateral sulcus angle (L) increases to about the same extent so that L + M the total sulcus angle is in the main unchanged

TABLE 3

Results of measurements on x ray pictures of the normal material mean values
For symbols see Fig 2 and for FC and MC see p 71

	100 normal females dx	sin	Diff dx sin	100 normal males dx	sin	Diff dx–sin	Diff female/male
l	10 08±0 13	9 11±0 17	0 97±0 26***	11 60±0 18	10 66±0 20	0 94±0 27***	−1 [illegible]2±0 26*** −1 [illegible]±0 26***
m	5 59±0 16	5 87±0 15	−0 28±0 22	6 40±0 16	7 33±0 18	−0 93±0 24***	−0 81±0 23*** −1 46±0 24***
l/m	1 98±0 08	1 64±0 05	0 34±0 09***	1 [illegible]±0 07	1 55±0 05	0 40±0 09***	0 03±0 11 0 09±0 07
l−m	4 43±0 25	3 24±0 19	1 25±0 34***	5 13±0 24	3 33±0 27	1 97±0 36***	−0 70±0 35* −0 09±0 33
C_p	6 10±0 30	4 36±0 26	1 74±0 40***	5 95±0 36	3 83±0 30	2 12±0 40***	0 15±0 40 0 [illegible]3±0 40

C,	2 63±0 22	1 42±0 22	1 21±0 31***	3 09±0 21	1 78±0 21	1 31±0 30***	−0 46±0 30 −0 36±0 30
L	69 39±0 39	70 77±0 38	−1 38±0 54*	69 31±0 35	70 68±0 35	−1 37±0 50**	0 08±0 52 0 09±0 52
M	72 40±0 43	71 59±0 42	0 81±0 60	73 4 ±0 43	71 24±0 40	2 23±0 59***	−1 07±0 61 0 35±0 58
L+M	141 79±0 60	142 36±0 61	−0 57±0 86	142 78±0 51	141 90±0 54	0 88±0 74	−0 99±0 70 0 46±0 82
LC	65 29±0 9	65 93±0 88	−0 64±1 18	71 98±0 74	72 22±0 77	−0 24±1 07	−6 69±1 08*** −6 29±1 17***
MC	63 66±0 77	64 08±0 83	−0 42±1 13	70 49±0 72	70 71±0 73	−0 22±1 03	−6 83±1 06*** −6 63±1 10***
LC−MC	1 60±0 21	1 85±0 27	−0 25±0 34	1 49±0 26	1 51±0 32	−0 02±0 04	0 11±0 33 0 34±0 42

These now described changes can have two explanations either that l really has reduced and m increased with consequences also for the angles (Fig 11 B, p 48) or that the left femur stands somewhat more outwards rotated in the hip or the distal femur end somewhat more outwards torqued on the left side compared with the right (see Fig 11 C)

The dorsal condyle angle G_t gives information regarding this If there is torsion or rotation change this angle will reduce according to the figure and possibly become negative i e open medially If on the other hand it concerns a real reduction of l and an increase of m it will remain unchanged In Table 3, it can be seen that the average for G_t is less on the left side as a sign of the torsion or the rotation being changed

l + M which within reasonable limits are independent of rotation—torsion show no significant difference between right and left

The same tendency with difference on the right and the left side and about the same degree of statistical significance is found in the female material as well as in the male (see Table 3)

For the normal material the ratio l/m has also been calculated (see Table 3) and it shows that on the right side the medial condyle is about half as high as the lateral condyle in both male and female on the left side the medial is about two thirds as high as the lateral condyle

LC and MC have faults too great to be able to give positive information about the relatively small differences dealt with here

Thus there exists in both female and male a statistically significant difference between right and left side This difference seems to be due to an increased outwards rotation or torsion on the left side This difference on the right and the left side I have not seen described earlier On a usual axial X ray picture which thus depicts only the anterior part of the condyle portion this asymmetry can be rather pronounced Here one cannot see p 57 decide the reason for this levelling of the two condyle heights in the same way as when one x ray photographs both the anterior and the posterior condyle portions at the same time Those authors who have found among their patients that left sided dislocations are somewhat more common have mentioned nothing about this asymmetry on the x ray picture

Difference between the right and the left side of the body is not unusual Martin states in his Lehrbuch der Anthropologie how usual it is

to find a difference in the length of the arms only 18 per cent of German soldiers had both arms the same length in 82 per cent the length differed In 75 of this 82 per cent the right arm was longer in the remaining 7 the left was longer Martin sees this as the result of the right hand being trained and developed more The legs too are often asymmetrical but here according to Martin the left leg is usually the longer Schreiner (1935) Sauser (1938) and Vogler (1962) find asymmetry in the femur on the right and the left side Allen (1926) describes a more advanced ossification in the metacarpal bones usually in the right hand of the right handed Pryor (1936) Schmid & Halden (1949) and Scheller (1960) however find so insignificant a difference of ossification in children on the right and the left side (shoulders hips and knee joints) that it can be explained by a few persons with pathologic subclinical changes being recorded in their large normal material

The difference found in the present investigation between right and left side must be taken into account when comparing the results of measurements of knee joints in different groups and the same side must always be used for comparison

3 *Dissimilarities between male and female* Male and female show differences between them which however concern mainly the measured lengths l m LC and MC l and m are statistically significantly higher in male LC and MC are also but for these latter considerable reservation are valid as earlier mentioned The angles C_p, C_t L and M are mainly alike or show statistically very uncertain differences between male and female

Thus in the main the distal femur end has the same form in female and male but is somewhat more delicate in the female

4 *For other results* see Table 3 Normal values for l m C_p L and L+M are found also in col 1 and 2 in Definitions Abbreviations

C Summary

By my methods 100 female and 100 male without subjective difficulties and with apparently normal configuration regarding legs and knee joints were examined roentgenologically

Differences so pronounced exist between the right and the left side as can be seen on the x ray pictures of both male and female that the

two sides must be treated independently and comparison between the patient material and the normal material must always be made on the same side This difference seems to be due to changed torsion or rotation conditions

Normally differences also exist between male and female the distal femur end in the female being more delicate than in the male They are in the main similar and occupy the same skeletal position regarding rotation and torsion

Age and body length do not appear to influence the given measure values

For the results see Table 3

CHAPTER VII

The patient material. General description

A. Composition of the material

The intention with this investigation was to collect a patient material so large that certain roentgenological measurements could be made, arranged statistically and compared with a normal material investigated under the same conditions. I have *not* aimed at any clinical follow-up series.

The material consists of patients who had been treated for recurrent dislocation of the patella in the orthopedic clinics in Lund, Malmö, Hälsingborg and Kristianstad, at the Orthopedic Hospital in Copenhagen and at KASG (Köpenhamns Amts Sygehus in Gentofte) during the years 1945 to 1961.

Swedish patients. All patients who had attended hospital as inpatients in Lund, Malmö and Hälsingborg were recalled for examination as well as the two male patients who had been inpatients at the Orthopedic clinic in Kristianstad since the clinic started about ten years ago. In order to get the *male* group large enough, I tried to get as many as possible by writing repeatedly to those I had not heard from after the first summons. I also included in the investigation two male outpatients who attended the Orthopedic clinic in Lund during the time of the investigation, both of whom were obvious operation cases. The female patients were usually recalled only once after the first summons. **The sex proportion in my material is thus artificial.** All patients from the Hälsingborg clinic are included in the clinical follow-up series published by Jerre & Knutsson (1958). Some of the patients from Lund are included in Ståhl's work concerning fractures at dislocation of the patella (1950).

The Swedish patient material thus included 53 female and 27 male whom I examined both clinically and roentgenologically in 1962, using

the methods described in Chapter V. Two female and two male patients were examined in the Roentgen diagnostic clinic of the Karolinska Sjukhus, the others in the Orthopedic clinic and the Roentgen diagnostic clinic II in Lund.

Danish patients. The patient material from Copenhagen differs somewhat from the Swedish. I based my investigations on Thestrup Andersen's material (see p. 13). In order to equate the age of this material to that of the Swedish, I took patients chiefly from the years 1915—51. Thus I examined ten female and nine male. To these I was able to add two female and three male treated by Thestrup Andersen after 1955 at KASG (Köpenhamns Amts Sygehus in Gentofte) and 16 female and 11 male who since 1951 (after Thestrup Andersen had finished collecting his patient material) had been treated for recurrent dislocation of the patella in the Orthopedic Hospital in Copenhagen. Thus the Danish material contained 10+2+16=28 females and 9+3+11=23 males.

All patients in the Danish material I personally examined clinically and roentgenologically (special pictures) in autumn 1962 in the x-ray department of the Orthopedic Hospital in Copenhagen.

The composition of the material appears in Table 4.

The Swedish patients, except for the two males already reported, have all been treated as *inpatients* in the respective clinics and can be regarded as homogeneous material because the inpatient indications in the clinics, which have throughout had the same principals, have been largely uniform. The Danish material contains both *inpatients and outpatients*. Because the hospitalization and operation indications accord

TABLE 4

Number of patients, sex and treatment clinic

	Lund	Malmö	Hälsingborg	Kristianstad	Copenhagen	Total
♀	38	12	3	—	28	81
♂	16	2	7	2	23	50
♀ + ♂	54	14	10	2	51	131

The sex proportion is artificial (see p. 87). The above figures are not representative of the number of patellar dislocations that have during 1915—60 been treated in the respective clinics.

ing to what I have found in records and from discussions with Danish colleagues are largely the same as for the Swedish clinics it is reasonable to assume that the Danish material includes some relatively mild cases However all of them fill my requirements according to the definition of recurrent dislocation of the patella An expression of this is the operation frequency in the Swedish material only 18 out of 104 dislocated knees are not operated upon (=17 %) whereas in the Danish material no less than 41 out of 75 dislocated knees have been left unoperated (=55 %)

The entire material thus contains 81 females and 50 males and once again it must be pointed out that when collecting material I have made special efforts to expand the male material therefore the sex proportion in my total material is artificial

The right knee in a female patient and one in a male patient has been partly excluded in the discussions Because of severe deformans troubles the female who had a double sided dislocation had the right patella removed in 1955 and the left in 1957 Osteo arthrotical changes so advanced existed on the right side that it was impossible to carry out any measurements on the x ray picture with any degree of accuracy This right knee is excluded from all discussions based upon measurements on the x ray picture but is found in those instances where the clinical information is the essential The male patient had a severe rest condition after polio in the right knee and dislocation of the patella in the left knee His right knee has not been included in the x ray measurements It was atrophic and deformed whereas the left seemed to be without any noticeable fault His polio damaged right knee is excluded from all tables and discussions whereas the left is included in calculations based upon measurements on x ray pictures but not in those instances where clinical information and findings are a basis for ananlyzing the condition right—left

B *Different classifications of the patient material in the continued analysis*

The starting point for my investigation is the femoral dysplasia and its possible connection with the clinical picture The following clinical factors have been analyzed regarding this connection and have been a

basis for classifying or attempts at classifying the patient material into different groups

A Right—left—bilateral dislocation and the non dislocation knee (Chapter VIII)
B Age at onset operation and follow up (Chapter IX)
C Family occurrence of the condition (Chapter X)
D Trauma (Chapter XI)
E Patella alta (Chapter XII)
F Dislocation frequency (Chapter XIII)
G Prognosis (Chapter XIV)

The question of what importance the valgus position in the knee has for dislocation of the patella has been the object of several discussions which have become completely dominated by the skeletal valgus position However as has been shown (see p 30 ff) it is the angle (called by me the Q angle) occurring in the extensor mechanism that is important Changes in this Q angle can be due to among other things skeletal changes changes of the origin and insertion of the muscles and of the ligaments and some neuro muscular damage with the balance in the quadriceps upset as a consequence The question of on one hand the relation between the valgus position in the knee and the Q angle and on the other the dislocation of the patella is considerably more complicated than what has so far been generally imagined However in my opinion a more close analysis of these conditions lies beyond the scope of my investigation

C *Summary*

131 patients with recurrent dislocation of the patella (81 female and 50 male) have been collected from the orthopedic clinics in Southern Sweden and Copenhagen (Denmark) and examined roentgenologically and clinically

At the further analysis of the femoral dysplasia different classifications of the patient material are used as basis and the different principles of these classifications are reported

CHAPTER VIII

Right left bilateral dislocations The non dislocating knee

A General classification according to the symptoms in each knee

The patients were classified into unilaterally dislocating and bilaterally dislocating groups

Unilateral dislocations

Right side or left—which has the greater tendency to dislocate? A low lateral condyle has been mentioned by many as one of the most usual causes of recurrent dislocation of the patella

Some authors have also shown that among *unilateral* dislocations a certain predominance exists for the *left side* Thus Marion & Barcat (1950) report 54 per cent of about 300 unilateral dislocations on the left side Thestrup Andersen (1955) 53 per cent of 201 Sjovall (1943) 69 per cent of 26 and finally Bohi (1957) 62 per cent of 30 The reported difference is in every material considered independently small or uncertain However as those authors (who with larger material reported unilateral dislocations as right or left side) *all* find a left side dominance it gives the figures an increased importance

In my *normal* material a significant difference was shown between right and left side the height of the lateral condyle above the sulcus bottom (l) was lower on the left side whereas the medial height (m) was higher on the left side The changes in the angles argue that this change was due to the left distal femur end standing rotated or torqued outwards i e illusory dysplasia of the femur

This assymetry could possibly explain the left side dominance in recurrent dislocations of the patella that is pointed out by some authors In order to investigate these conditions I have classified the patient material into 1 right side dislocating 2 left side dislocating and 3 bilateral dislocating and have further analyzed these three groups The classification is shown in Table 5

TABLE 5

The patients classified according to luxating side
(One polio patient excluded from the material—see text)

	Number of patients Unilateral dx	sin	Bilat	Number of luxating knees dx	sin
♀	27	23	31	58	54
♂	17	15	17	34	32
♀ + ♂	44	38	48	92	86

The proportion given earlier of approximately one third right one third left and one third bilateral dislocating agrees rather well No predominance occurs for the left side among the unilaterally dislocating patients

The non dislocating knee Rather pronounced troubles often occur in the unilaterally dislocating patients in the form of feelings of instability in the non dislocating knee a feeling that it is about to collapse it feels as the other knee did before it went out of joint and similar comments These knees are here referred to as *unstable knees*

Some patients are subjectively completely trouble free in the non dislocating knee These are called *sound* knees If the knee joints are classified according to these principles the material appears as seen in Table 6

The table shows that in 82 patients with unilateral dislocations no less than 30 (37 %) have troubles from the non dislocating knee (9 right 21 left)

Bilateral dislocations

In bilaterally dislocating patients one can as a rule distinguish a dominant side i e that which has usually dislocated more often and given more trouble This side usually dislocated first If the bilaterally dislocating patients are classified with regard to the dominant side and the onset side the material appears as shown in Table 7

One finds that in bilateral dislocations the left side dominates usually

TABLE 6

Total knee joints in the patient material (luxating or non luxating) classified into the groups "luxating" "unstable" and "sound"
One male polio patient excluded. The sex proportion in the material is artificial

	Knees of patients luxating unilaterally									Knees of patients luxating bilaterally			Total number of knees		
	"Luxating"			"Unstable"			"Sound"								
	dx	sin	total	dx	sin	total	dx	sin	total	dx	sin	total	dx	sin	total
♀	2	23	50	4	16	20	19	11	30	31	31	62	81	81	162
♂	17	15	32	5	5	10	10	12	22	17	17	34	49	49	98
♀ + ♂	44	38	82	9	21	30	29	23	52	48	48	96	130	130	260

nearly twice as often as the right and more than twice as often it dislocates first

These differences between right and left side are statistical probable (*)

TABLE 7

Dominant side and side of onset in 48 bilaterally luxating patients
The meaning of "dx≈sin" is that both sides have been equally troublesome and began at about the same time

	48 patients luxating bilaterally					
	Dominant side			Side of onset		
	dx	sin	dx≈sin	dx	sin	dx≈sin
♀	9	15	7	4	10	17
♂	3	7	7	4	7	6
♀ + ♂	12	27	14	8	17	23

B Results of the measurments on x ray pictures of right, left, and bilaterally dislocating patients

The results of the measurements appear in Table 8 (common to female and male) 9 10 11 and 12 (female) and 13 14 15 and 16 (male)

Female and male no change of rotation torsion

In Table 8 the values of the dorsal condyle angle C_t are reported No significant difference occurs in the dorsal condyle angle between normal material and different patients groups

The posterior condyle plane (see p 20) is in the position that my patients assume not horizontal The femur is rotated inwards a few degrees (between 1 25 and 3 10 degrees) This concerns female as well as male the normal material as well as patients with dislocation of the patella and right as well as left side

In the patient material a similar difference between right and left is seen as in the normal material on the right side C_t is throughout greater as a sign that the right femur stands more inwards rotated or inwards torqued than the left

The rotation and torsion conditions are thus mainly the same for the normal material and the patient material and *in case some differences have been indicated in the formation of the sulcus in patients with recurrent dislocation of patella this is not due to changed torsion or rotation* as maintained by several authors (Dreesmann 1908 Hubscher 1909 Luckert 1919 Hohlbaum 1921 and Strube 1934)

Female

Column 5 Table 9 which concerns females with *unilateral right side dislocations* shows that the mean value for l (i e the height of the lateral condyle above the sulcus bottom) is 2 15 ± 0 55 mm less than in the normal material this difference is highly significant (***)

m is 1 85 ± 0 42 mm less (***) whereas C_p shows *no significant* change Both L and L + M are larger in the dislocating knees these differences are statistically highly significant (***)

These measurements show that the height of the condyles above the sulcus bottom is reduced in the dislocating knees This results in an increase of the sulcus angle L + M The reduction of the condyle height

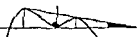
TABLE 8

Mean values for the dorsal condyle angle C_t in the normal material compared with different groups in the patient material females and males

Col	1	2		3 (1–)	4		(1–4)	6		7 (1–6)	8		9 (1–8)
	Normal material	All knees in patient material	No	Diff normal — all knees	All luxating knees	No	Diff normal — luxating knees	Unstable knees	No	Diff normal — unstable knees	Sound knees	No	Diff normal — sound knees
♀ dx	[illegible]±0 2[illegible]	2 [illegible]6±0 26	80	−0 13±0 34	2 75±0 30	57	−0 12±0 37	2 [illegible]0	4		2 84±0 5[illegible]	1[illegible]	−0 21±0 [illegible]
♀ sin	1 42±0 22	2 00±0 31	81	−0 5[illegible]±0 38	2 25±0 3[illegible]	[illegible]4	−0 83±0 43	1 2[illegible] ±0 [illegible]6	16	0 17±0 79	1 [illegible]1±0 [illegible]2	11	−0 50±0 66
♂ dx	3 09±0 21	2 88±0 32	49	0 21±0 38	3 03±0 41	34	0 06±0 4[illegible]	1 40	5		3 10±0 53	10	−0 01±0 57
♂ sin	1 78±0 21	1 80±0 28	50	−0 02±0 35	1 97±0 38	33	−0 19±0 43	2 20	[illegible]		1 17±0 37	12	0 61±0 43

TABLE 9

Measured results of unilaterally luxating females
Comparison with the normal material. Mean values



Col	1	2	3	4	(1–3)	6 (2–4)	7	8	9 (1–7)	10 (2–8)
	100 normal females		Unilat (right) luxation		Diff normal unilat (right) luxation		Unilat (left) luxation		Diff normal unilat (left) luxation	
	lx	sin	lx (27)	sin (27)	dx	sin	lx (23)	sin (23)	dx	sin
l	10 09±0 19	9 11±0 17	7 93±0 ›2	7 85±0 19	2 1ɔ±0 5ɔ***	1 ?6±0 43**	7 57±0 ɔ3	5 78±0 67	2 ›1±0 ›6***	3 33±0 6?***
m	ɔ ɔ9±0 16	ɔ 87±0 1›	3 74±0 39	4 9±0 44	1 85±0 42***	1 ?8±0 46**	4 04±0 5?	3 ?6±0 59	1 55±0 ɔ8***	1 91±0 ?0***
C_1	6 10±0 30	4 J0±0 26	5 74±0 88	4 33±0 79	0 3?±0 ?3	0 03±0 83	4 74±0 72	2 74±1 17	1 36±0 77	1 62±1 20
l	69 39±0 39	?0 77±0 38	75 44±0 93	74 89±0 ?3	−? 05±1 01***	−4 12±0 92***	7ɔ 04±1 01	77 65±1 21	−› 65±1 08***	−6 98±1 27***
l+M	141 79±0 60	14› 36±0 ?1	152 5›±1 67	149 ?3±1 ɔ4	−10 73±1 77***	−6 27±1 ?6***	150 17±2 30	155 22±2 14	−8 38±2 38***	−12 96±2 93***

t test lowers the significance by one star

occurs uniformly i e affects the lateral condyle and the medial proportionately as is apparent from the fact that C_p is in the main unchanged

Column 6 in the same table shows that also the *left (the non dislocating) knee* in these 27 females with only right side dislocations displays statistically significant changes of the same type as the right except that they are somewhat less pronounced l and m are less than normal C_p is without significant difference and L and L+M have increased

The corresponding values in the females who showed *dislocations in only the left knee* 23 are found in Table 9 col 9 and 10 This shows that the knees have the same changes as those just described in the right side dislocation (smaller l and m larger L and M) and this refers to dislocating (left) knees (col 10) as well as non dislocating (right) knees (col 9)

The group non dislocating knee (see Table 6) can be classified into *unstable* knees and *sound knees* sound knees means knee joints which to the patients have subjectively been completely trouble free and in which there has never been any feeling of instability

The measured values of these sound knees in 30 females (19 right side 11 left) were analyzed and compared with those of the normal material The results can be seen in Table 10

Statistically significant differences in all reported magnitudes are found on the right side (col 5) except for m and C_p where the change is probable and not significant respectively A check of the significance by the t test gives the same significance for all values This means that l as well as m is less than normal in the completely trouble free right knee in these left side dislocating patients l seems to have reduced proportionally somewhat more than m The lateral sulcus angle L and the total sulcus angle L+M have increased

On the left side there are only 11 completely trouble free knees in right side dislocating patients Here the changes are less pronounced and the group is smaller The tendency is the same (col 6 Table 10) as for the 19 sound right knees however it is only when is concerns L and L+M that the difference becomes statistically probable (*) The t test gives the same result

In Table 11 are found the *comparison values partly for the bilaterally dislocating knees (col 5/6) partly for all dislocating right knees* (uni

TABLE 10

Comparison of the measured results for normal material on one hand, and sound (subjectively trouble free) knees in unilaterally luxating females on the other
Mean values

Col	1	2	3	4	5 (1–3)	6 (2–4)
	100 normal females		"Sound" knees in unilat luxating females		Diff normal – Sound females	
	dx	sin	dx (14)	sin (11)	dx	sin
l	10 08±0 13		7 68±0 62		2 40±0 65***	
		9 11±0 17		9 18±0 59		0 93±0 61
m	5 59±0 16		4 16±0 67		1 43±0 69*	
		5 87±0 15		5 00±0 62		0 87±0 64
Cp	6 10±0 30		4 84±0 84		1 26±0 89	
		4 36±0 26		4 27±1 23		0 09±1 26
L	69 39±0 38		74 79±1 19		–5 40±1 25***	
		70 77±0 38		73 82±1 33		–3 05±1 38*
L+M	141 79±0 60		149 21±2 69		–7 42±2 76**	
		142 36±0 61		146 73±1 96		–4 37±2 0 *

lateral right dislocations plus right knees in the bilateral dislocations—col 9) *and partly for all dislocating left knees* (unilateral left dislocations plus left knees in bilateral dislocations—col 10)

The bilateral dislocations (col 5/6) show highly significant changes l is fully 3 5 mm less m nearly 2 5 mm less in the dislocating knees than in the normal material L and L+M have increased strongly The changes are of the same type and magnitude in both sides

In column 3 Table 12 I have compared column 3 Table 9 (right side in unilateral right dislocations) with column 3 Table 11 (right side in bilateral dislocation) and find that the latter show *more pronounced dysplastic changes but the difference is statistically uncertain*

The same tendency is found (col 6 Table 12) if a corresponding comparison is made for the left side (left side in unilateral left dislocation compared with left side in bilateral dislocation)

In column 4 Table 12 I have compared the left non dislocating knee in unilateral right dislocating females (col 4 Table 9) with the left

TABLE 11

Measured results of females luxating bilaterally and bilaterally/unilaterally
Comparison with the normal material Mean values

(I	1	2	3	4	5(1–3)	6(–4)	7	8	9(1–)	10(2–8)
	100 normal f males		Bilat luxati ns		D ff normal – l l u luxations		All luxating k	s (unilat or l il it)	Diff n rmal – all luxating kn s	
	dx	sin	dx (30)	sin (31)	lx	si	lx (7)	sin (l)	lx	sin
I	10 09±0 13	9 11±0 17	6 47±0 66	3 33±0 4	3 61±0 68***	3 72±0 48 **	7 16±0 43	5 6±0 38	2 92±0 4 ***	3 5±0 42***
m	5 59±0 16	5 87±0 15	3 33±0 35	3 42±0 32	2 26±0 38***	2 4 ±0 3***	3 53±0 26	3 65±0 31	2 0f±0 30***	2 22±0 34***
p	6 10±0 30	4 3f±0 26	4 40±0 88	2 81±0 8	1 0±0 93	1 5 ±0 0*	5 04±0 f2	2 9±0 f	1 06±0 61	1 59±0 6*
I	69 39±0 38	0 ±0 38	77 4 ±1 29	79 23±0 9	–9 08±1 28***	–8 4f±1 05**	51±0 4	8 5f±0 6	–7 12±0 9* *	–7 ±0 8***
I+M	141 79±0 f0	142 36±0 61	153 33±2 14	155 57±1 64	–11 54±2 22***	–13 61±1 5***	152 9 ±1 37	155 65±1 30	–11 16±1 50***	–13 29±1 44***

TABLE 12

Comparison of measured results (mean values) of unilaterally luxating females on one hand and bilaterally luxating on the other

Col	3	4	5	6
	Diff betw een unilateral (right) luxation and bilateral		Diff between unilateral (left) luxation and bilateral	
	dx	sin	dx	sin
l	1.46±0.84	2.46±0.60***	1.10±0.85	0.39±0.81
m	0.41±0.52	1.17±0.54*	0.[illegible]1±0.66	0.[illegible]4±0.66
C_p	1.34±1.24	1.52±1.02	0.34±1.14	−0.07±1.34
t	−2.03±1.53	−4.34±1.22***	−2.43±1.58	−1.[illegible]8±1.56
t+M	−0.81±2.71	−[illegible].34±2.25**	−3.10±3.14	−0.75±2.70

knee in bilaterally dislocating (col 4 Table 11) We see that despite the left (non dislocating) knee s having pronounced dysplastic changes it differs significantly from the left knee in bilaterally dislocating patients the latter having even more pronounced dysplasia

A corresponding investigation (col 5 Table 12) for the right non dislocating knee in unilateral left dislocating females (col 7 Table 9) compared with the right knee in bilaterally dislocating (col 3 Table 11) shows the same tendency but the differences are non significant

Male

Tables 13 14 15 and 16 show the measured results for the *male patients* The male patient material is not so large as the female there fore mean errors are somewhat larger

In column 3 Table 13 (i e right knee in *unilateral right dislocating patients* compared with the normal material) the same changes are observed as in the corresponding female group l and m have reduced

TABLE 13

Measured results of unilaterally luxating males
Comparison with the normal material Mean values



Col	1	2	3	4	5 (1–3)	6 (2–4)	7	8	9 (1–7)	10 (2–8)
	100 normal males		Unilat (right) luxation		Diff normal unilat (right) luxation		Unilat (left) luxation		Diff normal unilat (left) luxation	
	dx	sin	dx (17)	sin (17)	dx	sin	dx (1)	sin (16)	dx	sin
l	11 60±0 18	10 66±0 20	6 94±0 60	8 06±0 68	4 76±0 63***	2 60±0 71***[1]	9 33±0 57	8 00±0 61	2 67±0 60***	2 66±0 64***[1]
m	6 40±0 16	7 33±0 18	4 24±0 53	5 18±0 50	2 16±0 55***[1]	2 15±0 53***	4 93±0 40	4 39±0 23	1 47±0 43***[1]	2 95±0 34***
C_p	5 95±0 26	3 83±0 30	3 35±0 90	3 29±0 75	2 60±0 94**	0 54±0 81	5 00±0 69	4 13±0 87	0 95±0 73	−0 30±0 [illegible]
I	69 31±0 35	70 69±0 35	77 18±1 06	75 89±1 2[illegible]	−7 87±1 12***	−5 20±1 27***[1]	73 80±1 08	75 31±1 34	−4 49±1 14***[1]	−4 63±1 39***[1]
l+M	142 78±0 51	141 90±0 54	154 24±2 07	149 94±2 16	−11 46±2 13***	−8 04±2 23***[1]	149 31±1 [illegible]	151 06±1 50	−6 55±1 73***[1]	−9 16±1 59***

[1] t test lowers the significance by one star

highly significantly (***) I and I +M have increased The decrease in the male patients of C_p (statistically significant) as appears in Table 13 was however only hinted at in the female material

The *non dislocating knee* is in the males the seat of dysplastic changes (col 6 Table 13) highly significant but not so fully pronounced as on the dislocating side

It is seen in columns 9 and 10 Table 13 that the same condition as already described for the unilaterally right dislocating patients also refers to the *unilaterally left dislocating patients* i e both the dislocating and the non dislocating knee are seats of dysplastic changes

As in the female patient material the sound *male knees* i e those non dislocating knees that are subjectively completely trouble free have been assembled and the measured values have been compared with the normal material This concerns 10 sound right knees in left dislocating patients and 12 sound left knees in right dislocating patients The results appear in Table 14

TABLE 14

Comparison of the measured results for normal material on one hand and sound (subjectively trouble free) knees in unilaterally luxating males on the other
Mean values

Col	1	2	3	4	5 (1–3)	6 (2–4)
	100 normal males		Sound knees in unilat luxating mal		Diff normal — sound mal s	
	dx	sin	dx (10)	sin (12)	dx	sin
I	11 60±0 18	10 66±0 20	9 00±0 68	8 08±0 87	2 60±0 70***[1]	2 58±0 89**
m	6 40±0 16	7 33±0 18	4 70±0 50	5 25+0 53	1 70±0 53***[1]	2 07±0 56**
Cp	5 95±0 26	3 83±0 30	5 30±0 78	3 25±0 97	0 65±0 82	0 58±1 01
I	69 31±0 35	70 68±0 35	74 00±1 38	75 33±2 13	−5 [illegible]±1 50***[1]	−4 [illegible] ±2 16*
I+M	142 78±0 [illegible]1	141 90±0 54	149 80±2 36	149 25±2 92	−7 02±2 41**	−7 35±2 97**

[1] t test lowers the significance by one star

On the right side (col 5) a clear difference exists l m and I show a highly significant difference (***) and also L+M (**) whereas C_p shows no significant difference t test reduced the three star significance to two star but has no effect upon the two star

Also on the left side where there are 12 "sound knees in right side dislocating males the sound side is the seat of dysplastic changes (col 6)

Columns 5 and 6 Table 15 show that the dysplastic changes in the *bilaterally dislocating male patients* are statistically significant

In Table 16 the measured values of the unilaterally dislocating males are compared with the corresponding values of the bilaterally dislocating Between the dislocating knees in the two groups (col 3 and 6 Table 16) no significant differences exist and the tendency is not uniform As in the female patients the non dislocating knee is somewhat less dysplastic than the corresponding dislocating knee (col 4/5 Table 16) but the differences are non significant

TABLE 16

Comparison of measured results (mean values) of unilaterally luxating males on one hand and bilaterally luxating on the other

Col	3	4	5	6
	Diff between unilat. (right) luxation and bilateral		Diff between unilat (left) luxation and bilateral	
	dx	sin	dx	sin
l	− 0 94 ± 1 12	1 06 ± 1 10	1 05 ± 1 11	1 00 ± 1 05
m	− 0 70 ± 0 95	− 0 11 ± 0 81	− 0 01 ± 0 89	− 0 91 ± 0 [illegible]0
C_p	− 0 36 ± 1 25	0 82 ± 1 35	1 29 ± 1 10	1 72 ± 1 42
L	1 30 ± 2 04	− 1 65 ± 2 02	− 2 08 ± 2 08	− 2 2[illegible] ± 2 10
L+M	3 65 ± 4 38	− 1 35 ± 3 63	− 1 26 ± 4 20	− 0 23 ± 3 29

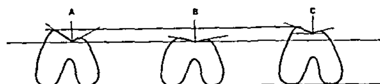


Fig 26 This shows how the same changes in L m C_p L and L+M can arise either by an actual lowering of the height of the condyles above the sulcus bottom (B) or by raising the sulcus bottom (C) A = normal conditions

approximate and the approximation is partly of uncertain magnitude therefore they ought to be appraised with the greatest care

Table 17 shows LC and MC partly in the normal material partly for all dislocating right knees (unilateral+bilateral) and partly for all dislocating left knees (unilateral+bilateral) in females Table 18 shows the same thing in males

Column 5 and 6 in the respective tables show that the mean for both LC and MC is significantly (**) or highly significantly (***) greater in the dislocated knees this refers to both males and females (Exception On the right side the difference between the normal material and the dislocated knees concerning LC is in males statistically probable (*))

LC and MC are approximate expressions and must be appraised most carefully Because the differences are of the just reported magnitude I however consider it justified to say that my investigations argue against the idea that the lowering in the height of the condyles above the bottom

TABLE 17

The extension of lateral and medial condyle ventro dorsally expressed by LC and MC (see p 71) in normal and in luxating knees

Mean values females LC=lateral condyle MC=medial condyle

Col	1	2	3	4	5(1–3)	6(2–4)
	100 normal females		All luxating knees of respective sides		Diff normal — luxating knees	
	dx	sin	dx ( )	sin (54)	d	sin
LC	65 20 ± 0 59		73 79 ± 2 16		− 8 5? ± 2 30***	
		65 93 ± 0 88		73 02 ± 1 68		− 7 09 ± 1 89***
MC	63 66 ± 0 57		73 18 ± 2 08		− 9 52 ± 2 22 **	
		64 08 ± 0 83		74 20 ± 1 57		− 10 12 ± 1 96*

TABLE 18

Same as Table 17
Mean values for males

Col	1		3	4	5(1–3)	6(2–4)
	100 normal males		All luxating knees of respective sides		Diff normal — luxating knees	
	dx	sin	dx (31)	sin (33)	dx	sin
LC	71 98 ± 0 74		77 59 ± 2 52		− 5 61 ± 2 63*	
		72 22 ± 0 77		78 21 ± 2 13		− 5 99 ± 2 32**
MC	70 49 ± 0 72		78 32 ± 2 50		− 7 83 ± 2 60**	
		70 71 ± 0 73		78 06 ± 2 31		− 7 35 ± 2 42**

of the sulcus which can be established in patients with recurrent dislocation of the patella has been brought about by a real reduction of the ventro dorsal extension of the condyles and also argue that this levelling between the contours is brought about by the raising of the sulcus bottom

C *Summary*

About one third of the 130 patients had bilateral dislocations one third had right side one third had left side Of 82 patients with unilateral dislocations 30 (37 %) had troubles with the non dislocating knee in the form of feelings of instability In the bilaterally dislocating patients the left side is dominant (shows more symptoms) more often (12 right 22 left 14 both) and is usually also the side where the trouble starts (8 right 17 left 23 both)

In the actual x ray investigation position the distal femur end occupies mainly the same rotation or torsion position in patient material as in normal material The same tendency of the right femur to increased inwards rotation or torsion as seen in the normal material is also seen in the patient material In the dislocating knees of the *female* patients both the lateral and the medial condyle have reduced in height above the bottom of the sulcus (l and m have reduced on the dislocating side) L and L+M increased whereas C_p shows no statistical change

The dysplastic changes of the dislocating knee are more pronounced

if the patient dislocates bilaterally than if he does so unilaterally but the difference is statistically non significant

The non dislocating knee in the unilaterally dislocating shows significant dysplastic changes and even if only the completely trouble free knee joints are taken into account these too show significant dysplastic changes

In most instances similar changes are seen in the *male* patient material but because this is smaller the statistical significance becomes less

The possibility is discussed that these changes are not due to an actual reduction of the extension of the condyles in ventro dorsal direction but to a relative raising of the sulcus bottom

CHAPTER IX

Age at onset, operation, and follow up investigation (With special reference to the difference between the right and the left side)

A General clinical appraisal

Age of onset

The mean age of the patients at the first dislocation in the respective knee in different groups is reported in Table 19

The table shows among other things

1 The mean age of the first dislocation in unilaterally dislocating patients is 16 4 years for females and 16 3 for males in the bilaterally dislocating the first dislocation occurs at age 13 3 and 16 4 years respectively

2 The onset of the condition in the patient irrespective of whether it later becomes bilateral occurs in females at age 15 2 years and in males at age 16 3

This is a somewhat higher age of onset than is usually indicated Thus Marion & Barcat without separating females and males make a classi

TABLE 19

Mean age at first luxation in respective knee in all patients

		Unilateral luxation			Bilateral luxation				Age at onset All patients
		dx	sin	dx+sin	1st knee	2nd knee	dx	sin	
	No	27	23	50	31	31	31	31	81
♀	Mean age	16 8	15 9	16 4	13 3	18 0	16 9	14 4	15 2
	Range	10–[illegible]8	9–[illegible]	9–33	6–22	8–50	6–50	8–35	6–50
	No	17	16	33	17	1[illegible]	17	17	50
♂	Mean age	16 3	16 3	16 3	16 4	19 5	17 8	18 1	16 3
	Range	10–21	5–26	5–29	1–29	1–40	1–34	1–40	1–40

fication according to the age of onset with two peaks corresponding to age 5 years and 15 years Thestrup Andersen finds the mean age for females to be 14 2 years and for males 17 6 (10 females and 9 males are the same in the material of Thestrup Andersen as in that of mine)

3 In bilateral dislocations the onset age in females for the left knee is lower than for the right knee 14 4 and 16 9 respectively This difference is statistically suggestive but uncertain (2 5 ± 1 7 years)

Age at operation

Table 20 shows the age at operation for the different patient categories and also that the operation age of the males is throughout somewhat lower than that of the females

Of greater interest is the interval between the onset and the operation Table 21 shows among other things that the interval between age at onset and operation is about 9 years in females compared to about 6 years in males The explanation of this difference using the evidence from my material can only be conjectural

Thestrup Andersen in his material has found the same tendency even though instead he reports the interval between the first dislocation and the first visit to the doctor He finds that females wait on average 8 3 years before they visit the doctor and males 5 6 years He proffers no explanation for this difference between the sexes

Table 21 shows also that both males and females seem to go a longer time with the condition in the left knee than in the right

TABLE 20

Mean age of patient at time of operation in resp knee

		Unilateral luxations			Bilateral lux Bilateral op		Bilat lux & unilat op
		dx	sin	dx+sin	1st knee	2nd knee	
[illegible]	No	20	1	37	13	13	13
	Mean age	23 3	25 6	24 4	21 4	25 4	22 2
[illegible]	No	1	1	27		7	4
	Mean age	20 5	23 0	21 6	21 1	23 4	27 8

TABLE 21

Interval between onset and operation in resp. knee
Mean values

		Unilateral luxations			Bilateral lux. Bilateral op		Bilat lux & unilat op
		dx	sin	dx + sin	1st knee	2nd knee	
♀	No	[illegible]	1	[illegible]	13	13	13
	Mean values	7 6	10 1	[illegible]	8 6	9 9	9
	Range	0–20	0–28	0–28	0–33	0–33	0–31
♂	No	1	1	2			4
	Mean values	4 1	6 9	5 3	[illegible] 5	6	[illegible] 8
	Range	0–10	0–32	0–32	0–20	0– [illegible]	0–23

Age at follow up investigation

Table 22 shows the age at the follow up investigation in all patients Apart from a remarkable difference hard to explain between the age of unilateral left dislocations in females and in males (35 2 and 28 8 years respectively) no greater differences are found The mean age of the female patients was at the follow up investigation 34 6 years and of males 32 2 years

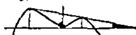
TABLE 22

Mean age at follow-up investigation
All patients

		Unilateral luxation		Bilat lux	Total patients
		dx	sin		
♀	No	[illegible]	23	31	81
	Mean age	32 9	35 2	35 5	34 6
	Range	15–34	19–60	15– [illegible]	15–74
♂	No	1	16	1	50
	Mean age	34 0	28 8	33 6	32 2
	Range	14–50	13–60	23–60	14–60

TABLE 25

Comparison of measured results for all knees (luxating or non luxating) in male patients where the condition began after and before age 17 years
Mean values



Col	3	4	5	6	7 (3–)	8 (4–6)
	All knees of patients where condition began after age 17		All knees of patients where condition began before age 17		Diff after age 17 — before age 1	
	dx (23)	sin (23)	dx (26)	sin (27)	dx	sin
l	8 57±0 47	7 91±0 44	7 27±0 68	7 48±0 66	1 30±0 83	0 43±0 79
m	4 91±0 46	5 17±0 41	4 50±0 50	4 78±0 41	0 41±0 68	0 39±0 58
C_p	4 48±0 69	3 26±>0 30	3 54±0 69	3 33±>0 30	0 94±0 97	−0 07±>0 4
I	74 39±0 82	76 26±>0 38	76 85±1 30	76 26±0 38	−2 46±1 54	0
I+M	150 13±1 92	149 87±1 71	152 65±2 80	151 52±2 20	−2 52±3 40	−1 65±2 51

The interval between onset and operation is longer for females than for males

The interval between onset and operation is longer for the left knee than for the right This applies to both females and males

The mean age at the follow up investigation was 34 6 years (females) and 32 2 years (males)

Patients in whom the condition has an early onset—for females before age 16 years for males before age 17 years—showed on the x ray picture more pronounced dysplastic changes than those whose onset occurred after the age mentioned The difference is significant in females and non significant in males

CHAPTER X

Family occurrence

As mentioned in Chapter III several authors have stated that recurrent dislocation of the patella often exists in or has been found among the patient s relatives

Bauer & Göttig (1936) have assembled from the literature 18 genealogical trees of families with dislocation of the patella where in some instances they have been able to trace the condition for five generations They consider the predisposition to dislocation of the patella to be dominantly hereditary with a stronger penetrance factor in the female side because of among other things the physiologically greater genu valgum

Also in the genetic text book of Touraine (1955) and Just (1940) the predisposition is considered to be dominantly hereditary Bauer & Göttig are of the opinion that extremely few instances of recurrent dislocation of the patella are clearly traumatically conditioned by far the most are congenital which in turn is due to inherited tendencies Bauer & Göttig establish the following criteria for the diagnosis congenital dislocation of the patella 1) low onset age 2) bilateral dislocation 3) no or only slight initial trauma 4) family occurrence of the condition 5) x ray *changes in the knee joint (genu valgum low lateral condyle small and* thick patella) 6) other congenital joint or bone changes occurring at *the same time such as dislocation of the hip deformity of the foot dislocation of the radius dislocation of the shoulder and above all a* general hypermobility in all joints The dislocation of the patella is according to these authors often only the most dramatic manifestation of a general malady of the joints

Marion & Barcat (1950) find dislocations in relatives of seven per cent of their patients without having specially investigated this detail *Thestrup Andersen who has directed attention to this matter finds*

such an occurrence in 20 to 25 per cent among parents, siblings or children. Thestrup Andersen thinks along the same lines as Bauer & Göttig and has in ten per cent of his approximately 300 patients found other congenital deformities (flatfoot, clubfoot, contractions, general laxness in the joints, etc.). He believes that a thorough investigation of patients with recurrent dislocation of the patella might disclose several non-symptom producing deformities.

Carter & Sweetnam (1960) have asked 111 patients with recurrent dislocation of patella wether they had relatives with joint troubles. This enquiry revealed 10 relatives suffering from patella dislocations.

All my patients have been asked whether they know of any occurrence of the kneecap jumping out of joint among their close relatives (children, siblings, cousins, nephews, nieces, parents, grandparents, aunts, uncles). Several patients have replied that relatives within that bracket have suffered from that condition. In cases of doubt, where the patient has not been absolutely certain, I have written and asked the relative concerned or studied the records.

TABLE 26

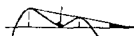
Comparison between all knees (luxating or non luxating) in patients without and with positive family anamnesis

Mean values for females

ol	3	4	5	6	7 (3−5)	8 (4−6)
	Patients with luxation (unilat or bilat) without pos family anamnesis		Patients with luxation (unilat or bilat) with pos family anamnesis		Diff without pos − with pos family anamnesis	
	dx (50)	sin (59)	dx (21)	sin (22)	dx	sin
	7 36 ± 0 19	6 51 ± 0 35	7 05 ± 0 74	5 82 ± 0 62	0 31 ± 0 74	0 69 ± 0 71
m	3 88 ± 0 50	4 12 ± 0 31	3 09 ± 0 35	3 55 ± 0 42	0 79 ± 0 61	0 57 ± 0 52
ε	4 83 ± 0 30	3 42 ± 0 26	5 29 ± 1 06	2 95 ± 1 10	− 0 46 ± 1 06	0 47 ± 1 10
l	5 76 ± 0 38	76 89 ± 0 70	77 00 ± 1 24	78 55 ± 1 04	− 1 24 ± 1 24	− 1 67 ± 1 25
l + M	151 14 ± 0 9	152 27 ± 1 32	155 00 ± 1 74	156 23 ± 1 48	− 3 86 ± 1 98	− 4 01 ± 1 98*

TABLE 27

Same as Table 26
Mean values for males



Col	3	4	5	6	(3−)	8 (4−6)
	Patients with luxation (unilat. or bilat.) without pos. family anamnesis		Patients with luxation (unilat. or bilat.) with pos. family anamnesis		Diff. "without pos." — "with pos. family anamnesis"	
	dx (39 st)	sin (40 st)	dx (10 st)	sin (10 st)	dx	sin
l	7 72±0 49		8 50±0 75		−0 78±0 90	
		7 43±0 49		8 [illegible]0±0 60		−1 27±0 78
m	4 87±0 39		4 00±0 58		0 87±0 70	
		5 05±0.32		4 60±0 64		0 45±0 72
C_p	3 54±0 54		5 70±0 68		−2 16±0 87 *	
		2 90±0 63		4 90±0 67		−2 00±0 92*
I	75 85±>0 35		75 10±1 48		0 75±>1 48	
		76 50±0 93		75 30±0 5		1 20±1 08
L+M	151 31±>0 51		152 10±3 21		−0 79±>3 21	
		150 78±>0 54		150 70±>0 54		0 08±>0 81

In this way 22 females and 10 males proved to have a family occurrence of the condition (24 %). (None of these 32 patients are included in Thestrup Andersen's material.)

These 22 females and 10 males with positive family anamnesis have been more closely examined with regard to Bauer & Gottig's criteria.

Bilateral dislocations occurred in 11 of the 32 patients with family occurrence of the condition. This is the usual proportion, i.e. about one third of the entire material.

The *age of onset* is for females 13.6 years and for males 16.5 compared with 15.2 and 16.3 respectively for all patients. This lower age of onset for females with family occurrence of the condition is statistically uncertain.

Concerning *trauma* the reader is referred to Chapter XI.

The *dysplastic changes* are shown in Table 26 (females) and 27 (males). It appears from columns 7 and 8 in Table 26 that l and m are smaller and L and L+M are larger in females with positive family

anamnesis but the differences are statistically uncertain Only for L+M on the left side is the limit probable significant (*) reached but t test gives lower value and no significance

For the male patients (Table 27) the tendency is rather irregular and the small material (10) makes it too hazardous to draw any conclusions

Summary

Of my 131 patients 32 (24 % — 22 females and 10 males) reported that a close relative had suffered recurrent dislocation of the patella The 22 female patients with positive family anamnesis showed somewhat more pronounced dysplasia than the other patients but this difference is statistically uncertain

In the small group of male patients (10) tendencies are uncertain and the smallness of the material permits no conclusions

CHAPTER XI

Trauma

Trauma as an etiologic element has earlier played a big role in the discussions of recurrent dislocation of the patella. The classification into congenital and acquired dislocations is one of the most generally accepted and in the latter group the so called traumatic dislocations have been *dominant. However, in recent years one has become in*creasingly aware of the difficulty in maintaining the borders between these two groups. This is partly due to *the difficulty in defining the* concepts congenital and traumatic in precisely this condition and partly due in most instances to a *combination* of congenital factors and trauma giving rise to the dislocation. Nikolai (1960) has indicated the difficulties these determinations give rise to from the point of view of insurance.

In the material presented here no so called traumatic single dislocations are included, which Thestrup Andersen, for instance, finds in 13 of his 315 patients. He finds a further 59 acquired dislocations, six being permanent (status after polio, large cicatrizations after extensive *operations or trauma on soft parts*) and three bilateral dislocations. These three patients had, concerning both knees, stated as cause violent *direct assault at the initial dislocation and Thestrup Andersen found* no dysplastic changes on the x ray pictures. Of the remaining 47 unilateral dislocations four were judged to be caused by recurrent hydrops whereas no less than 43 were considered to be caused by direct or indirect violence. In 14 of these Thestrup Andersen finds slight dysplastic changes on the x ray pictures but points out the difficulties in determining these because one moves on the border between the normal and the pathologic.

In my patient material I have tried to focus interest upon those who have suffered a clear and unmistakable violent action against the knee. I have not been able to introduce more than 5 females and 13 males (as expected more males than females).

Of these patients 1 female and 3 males dislocated bilaterally. None

of these bilaterally dislocating patients have reported a trauma to *both* knees. If one therefore excludes these patients, 4 females and 10 males remain. Of the 4 thus excluded 3 had moreover a family anamnesis.

The measured results for these 14 patients are reported in Table 28 A and B. It is remarkable that nine of the ten males have unilateral right dislocations (Is the right leg more exposed to trauma?)

As far as can be judged from the small material dysplastic values exist. Thus the sulcus angle (L+M) is throughout more than 150°, the mean for the 14 patients is more than 154°, i.e. about 12° higher than the mean of the normal material. Similar values occurred in the normal material, but were rare.

My normal material consists of 400 knees (female and male, right and left). As demonstrated earlier the sulcus angle L+M is about the same irrespective of sex and side. Of these 400 knees only 20 (5 %) had a sulcus angle L+M more than 150° and 9 an angle more than 154.

If one excludes the patients who have family occurrence of dislocation of the patella two females and eight males (10 patients) remain.

If one moreover excludes the patients who subjectively have clear instability in the non dislocating knee one female and six males remain. They have *a unilateral dislocation of the patella, are completely trouble free in the other knee, have no family occurrence of dislocation of the patella and have a clearly defined trauma in the anamnesis.* (Patient No. PK 101, PM 203, 204, 208, 302, 304 and 307.)

The measured results on the x-ray pictures of these seven patients are reported individually in Table 29.

It shows there that the female patient (unilateral left dislocation) has an almost normal height of the lateral condyle 1, a very high medial condyle m, which gives her a negative condyle angle C_p of $-3°$ on the dislocating side. She has moreover a small sulcus angle L+M mainly owing to the medial sulcus angle being so small. All these changes can be referred back to the high medial condyle. Right and left side are mainly alike.

All males six showed low or negative C_p and/or a large sulcus angle L+M and/or a low lateral condyle 1. *The changes affected both the dislocating and the sound side.*

The fact that the changes are bilateral argues strongly that the dysplasia is not secondary but existed before the dislocation and together with the trauma led to the dislocation.

TABLE 28 A

Measured results of unilaterally luxating patients with a clear trauma in the anamnesis Females
Mean values for col 1 2 and 4

Col	1	2	3	4
	100 normal females		Unilat luxation with trauma	
	lx	sin	lx (f)	sin (f)
l	10 08±0 1	9 11±0 17	8	9 67
m	5 59±0 10	5 97±0 15	3	7 33
C_p	6 10±0 30	4 36±0 26	5	— 0
I	69 39±0 38	70 77±0 38	78	80 33
L+M	141 79±0 60	142 36±0 61	156	152 67

TABLE 28 B

Same as Table 28 A Males
Mean values for col 1 2 and 3

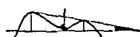


Col	1	2	3	4
	100 normal males		*Unilat luxation* with trauma	
	lx	sin	lx (3)	sin (1)
l	11 60±0 18	10 60±0 20	6 22	8
m	6 40±0 16	7 33±0 18	4 33	
C_p	5 95±0 20	3 83±0 30	2 33	4
I	69 31±0 3	70 68±0 3	78 67	75
L+M	149 78±0 1	141 90+0 54	155 11	1 0

TABLE 29

Measured results of unilaterally *luxating patients* with *trauma and* without *family anamnesis and* without *troubles in the non luxating knee*

One female (PK 101) with left sided luxation and six male with right sided luxation



Pat No	l dx	l sin	m dx	m sin	C_p dx	C_p sin	C_t dx	C_t sin	L dx	L sin	M dx	M sin	L+M dx	L+M sin
PK 101 (♀)	9	8	9	10	0	−3	1	0	76	73	62	61	138	134
PM 203	8	9	3	4	6	6	1	2	77	73	83	80	160	153
204	5	7	6	5	−2	2	0	2	79	78	75	76	154	154
208	2	4	2	4	0	0	3	−2	86	84	82	75	168	159
30[illegible]	8	8	5	5	5	3	−1	0	73	76	76	76	149	152
304	5	3	5	7	0	−3	1	1	79	85	76	72	155	157
30[illegible]	6	12	8	6	−3	8	−2	5	78	69	64	65	142	134

Of the seven patients who clinically filled the demand for a clearly traumatic dislocation thus only one (the female) did not show dysplastic changes on the x-ray picture. She had on the contrary a very strongly developed medial condyle whereas the lateral was apparently normal.

Summary

If in order to diagnose traumatic dislocation one requires an obvious direct trauma, unilateral dislocation with no troubles in the other knee, with no family anamnesis, only one female and six males fill the conditions. All males had unilateral right dislocations with dysplastic changes in *both* knee joints. This bilateral dysplasia argues strongly that the dysplasia is not secondary but existed before the dislocation and *together with the trauma* led to the dislocation.

CHAPTER XII

Patella alta

High standing patella or patella alta has by several authors been made responsible for recurrent dislocation of the patella The patella in these patients sits cranially to the sulcus and lacks bone support at the side when the knee is extended or lightly flexed The patella has therefore been considered more vulnerable and to dislocate more easily

If we consider patella alta to be *one* cause of dislocation and femoral dysplasia to be *another* it would be reasonable to expect that if we had a pronounced patella alta the femoral dysplasia would be less pronounced it being so to speak not necessary for the dislocation

If on the other hand we consider the dysplasia secondary to the dislocations either in the form of rubbing down or some other process the dysplasia ought to be quite as pronounced in the patella alta patients as in the non patella alta patients

In order to illustrate these conditions I intended to divide my patient material into two groups patella alta and non patella alta and to investigate whether there was any difference in the formation of the distal femur end in these two groups

However it proved difficult to get strict criteria for the diagnosis patella alta Most textbooks on roentgenologic diagnostics mention nothing about the condition or how it is diagnosed (*inter alios* Schinz *et al* 1952 Brailsford 1953 and Kohler & Zimmer 1956) The normally used method is that described by Blumensaat (1938) (see p 35) It has been used by *inter alios* Wiberg (1941) Furmeier & Breit (1952) and Thestrup Andersen (1955) It is quick and convenient and for practical purposes gives an idea of the position of the patella vertically However I have been unable to find published any normal material investigated by this method I found when measuring the angle between Blumensaat s line and the femur shaft (u Fig 8 p 36) in about 200 male knees that this angle could vary in different individuals between 60° and 27°

This must influence the determination of the position of the patella vertically and make the method inexact

Blumensaat's method presumes moreover a picture taken laterally with the knee at 30° flexion In my patient material I could get such pre operative pictures of only about 25 patients In most pictures taken laterally the knee was considerably more flexed To take fresh pictures laterally at the follow up investigation with the knee flexed 30°, would not have produced much information because most patients were operated and the patella pulled medially *distally*

Because a strict method of determining patella alta does not at present exist and the available x ray material did not permit with any degree of satisfaction an arrangement by the normally used method (Blumensaat's) I was compelled to relinquish the attempt to illustrate the question regarding the relation between patella alta and the femoral dysplasia

Summary

The available x ray material did not permit an analysis of the relation between patella alta and femoral dysplasia The normally used method of determining patella alta (Blumensaat's) is inexact

CHAPTER XIII

Dislocation frequency

With the guidance of the anamnestic information concerning the dislocation frequency the knee joints were classified into three groups

1 Joints with *few* dislocations—a total of 2 to 4 dislocations
2 Joints with *several* dislocations (the patient having had several but in the main not more than he can recall—usually 5 to 10 dislocations
3 Joints with *many* dislocations (the patient has lost count "it occurs once a week" and similar)

There is no distinct border between these groups

There is no reason why *one* knee of a patient should not belong to one group and the *other* knee to another group

Classified according to these principles the material appears as shown in Table 30

Comparison of the measured results of these three groups produced very uncertain results conflicting partly because some of the subgroups were so small (7 8 and 9 in the smallest) (See Table 30)

In order to get larger groups I combined the groups "several" and "many" into one group and compared its values with corresponding values of "few"

More pronounced dysplasia ought reasonably to produce more frequent dislocations The results are shown in Table 31 for females and 32 for males No statistically significant difference is seen (col 7/8) but with two exceptions all values (l m L and L+M) for both females and males and for both right and left side go in the expected direction i e the dysplasia is more pronounced in patients with frequent dislocations The exceptions are m for female on the right side and l for males on the left side but neither of these two unexpected differences is greater than fully half of its own mean error

TABLE 30

Classification of the luxating knee joints according to the number of luxations in resp. knee

	Few[1] lux. in knee dx	sin	Several[2] lux. in knee dx	sin	Many[3] lux. in knee dx	sin	Total N of knees dx	sin
♀	14	17	30	25	13	12	57	54
♂	13	17	13	9	8	7	34	33
♀ + ♂	27	34	43	34	21	19	91 + 87 = 178	

[1]= 1—4 luxations [2]=5—10 luxations [3]=>10 luxations
(Approximate figures)

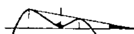
TABLE 31

Comparison of the measured results for luxating knees with "few" luxations on one hand and "several" or "many" on the other
Mean values for females

ol	3	4		6	7 (3–5)	8 (4–6)
	Luxating knees with few occurrences		Luxating knees with several or many occurrences		Diff. few—several or many occurrences	
	dx (14)	sin (1)	dx (43)	sin (37)	dx	sin
	71±0 66	6 53±0 67	6 98±0 52	5 38±0 48	0 73±0 84	1 15±0 82
	3 29±0 52	3 ,6±0 41	3 60±0 29	3 50±0 40	−0 31±0 60	0 17±0 57
p	6 36±1 40	4 00±1 78	4 60±0 45	2 27±0 65	1 76±1 47	1 ,8±1 44
	,5 93±1 02	, 00±1 30	,6 70±0 99	9 27±0 91	−0 77±1 42	−2 27±1.59
+M	157 1+2 11	1,3 6+1 5,	153 02±1 66	156 51±1 71	−0 31±2 69	−2 75±2.31

TABLE 32

Same as Table 31
Mean values for males



Col	3	4	5	6	7 (3−5)	8 (4−6)
	Luxating knees with few occurrences		Luxating knees with several or many occurrences		Diff. few − several or many occurrences	
	dx (13)	sin (1)	dx (21)	sin (1)	dx	sin
l	8 46±0 66	7 71±0 56	6 76±0 74	7 25±0 83	1 70±0 99	0 46±1 05
m	4 85±0 73	5 24±0 54	4 43±0 60	4 44±0 45	0 42±0 95	0 80±0 [illegible]0
C_p	4 39±0 85	3 00±0 91	3 00±0 81	3 62±1 09	1 39±1 17	−0 62±1 42
L	75 00±1 04	76 59±0 97	77 48±1 47	76 00±1 89	−2 48±1 80	0 59±2 12
L+M	150 85±3 21	149 82±1 78	153 38±2 94	152 63±2 [illegible]2	−2 53±4 29	−2 81±3 96

Summary

No connection between the degree of femoral dysplasia and dislocation frequency appears in the material reported here

CHAPTER XIV

Femoral dysplasia and prognosis of the function of the femoro patellar joint

A *Classification*

As earlier mentioned I have not sought to pursue a clinical follow up series because for one thing parts of my patient material were already published by Thestrup Andersen (1955) and Jerre & Knutsson (1958)

Several authors (*inter al* Fellander 1949 Marion & Barcat 1950 and Thestrup Andersen 1955) have stated that at recurrent dislocation of the patella the prognosis for the femoro patellar joint is worse if roentgenologic investigation discloses pronounced dysplastic changes there I therefore wanted to investigate the possible role played by any dysplastic changes I could measure on the x ray pictures for the prognosis

The knee joints have been classified—mainly according to the subjective troubles in the *femoro patellar joint* of the patients that were disclosed at the follow up series—into three groups

1 Good result The patient is completely or almost trouble free in the knee joint no dislocations and no feelings of instability is able to take part in sports and dancing no disability at work
2 Fair result The patient has troubles in the form of feelings of instability locking of the knee joint pain at exertion and hydrops He restricts himself regarding work sport and dancing because of the knee
3 Poor result Besides pronounced troubles according to the criteria of the fair group the patient still has dislocations

Post operative complications such as thrombosis peroneus paresis and similar have not influenced the classification because it was the function and the prognosis of the femoro patellar joint that interested me The result has been appraised as poor (referring to the femoro patellar joint) if one or more surgical attempts have failed and patellectomy has become necessary even though the function of the knee joint is good at the follow up examination

In order for a knee joint to qualify for this appraisal I have as far as *operated* knee joints are concerned required an observation period of at least two years after the operation and regarding *the non operated* a period of at least five years between the onset of the condition in the knee and the follow up examination. If I choose a shorter period than five years there is the risk of several *relatively fresh dislocations* which could soon need operations and thus perhaps be transferred from the group poor result (with dislocations) to either of the groups good or fair. How long the observation period should be can be a matter of opinion. Bearing in mind that males on average wait fully *five years and females fully eight years after the onset of the condition* before going to operation (see Table 21) a longer period than that chosen by me (five years) might be thought more suitable. These figures however are coloured by the fact that earlier there was more restriction in determining operation indications (the investigation included patients *treated from and including 1945*) nowadays the time between the onset of the condition and the operation is shorter.

The average time between the onset of the condition in the knees and the follow up investigation is thus for *the unoperated* females 21.2 years and for the males 19.3 years.

The observation period for *the operated* knee joints (with a minimum observation period of at least two years) is for females 10.2 years and for males 9.7 years.

The classification of the patient material based upon these details is shown in Tables 33, 34 and 35.

Table 33 shows that on average two thirds of the number of dis

TABLE 33

Number of luxating knees and number of operated knees considered at the appraisal of the function of the femoro-patellar joint at the follow-up investigation
Operated knees >2 years observation time, unoperated >5 years period sickness

	♀			♂			♀+♂
	dx	sin	dx+sin	dx	sin	dx+sin	
Operated	37	32	69	21	14	38	107
Non operated	17	17	34	8	10	18	52
Total	54	49	103	29	27	56	159

locating knee joints were operated on, whereas one third had a conservative therapy, such as elastic bandage, physical treatment, and in isolated instances orthopedic bandage treatment. In some instances, no treatment was applied. In the choice of surgical or conservative treatment there is no difference between right and left side or between female and male.

Table 34 shows the function of the femoro-patellar joint in dislocated knees at the follow-up investigation. Of 159 dislocating knees, operated or non-operated, 87 have become good, which is a better result than usual (see Chapt. III). However, as mentioned earlier, I have considered *only the function of the femoro-patellar joint, therefore a comparison* with other materials must be made with extreme caution.

Table 34 shows also that 14 knee joints, after having dislocated at least twice, have become completely symptom free and have not given the patient concerned any feeling of instability. Of these, three were patients with bilateral dislocations, and in addition to the successful operation in one knee they became well also in the non-operated knee. The explanation might be that an unloading of the non-operated knee had occurred when the patient became stable in the operated knee.

TABLE 34

The condition in luxating knee at follow-up investigation. The same observation time and period of sickness as in Table 33

For criteria of groups "good", "fair" and "poor" see text

	♀						♂						♀+♂		
	dx			sin			dx			sin			dx+sin		
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Operated	21	9	7	22	5	5	15	5	1	15	1	1	73	20	14
Non operated	4	5	8	6	5	6	2	1	5	2	2	6	14	13	25
Total	25	14	15	28	10	11	17	6	6	17	3	7	87	33	39

TABLE 35

The same as Table 34 but the material is classified according to right/left side

	♀+♂					
	dx			sin		
	Good	Fair	Poor	Good	Fair	Poor
Operated	36	14	8	37	6	6
Non operated	6	6	13	8	7	12
Total	42	20	21	45	13	18

Table 35 shows the distribution of the material into right and left dislocations No difference regarding operation frequency and prognosis is seen

B Measurements

The measured results of 87 knee joints referred to the group good (73 operated and 14 non-operated) on one hand were compared with 33 of the group fair (20 operated and 13 non operated) plus 39 of the group poor (14 operated and 25 non operated) on the other hand and are reported in Table 36 (females) and Table 37 (males)

Concerning the *females* it can be seen that on the right side (col 7 Table 36) no significant difference exists between these two groups

On the left side (col 8 Table 36) l and L differ statistically probably (*) the dysplastic changes being less pronounced among the good results (*On the right side these magnitudes go in the same direction* but do not go over the significance limit)

Concerning males we find a statistically significant difference on the right side (col 7 Table 37) where for example l is on average 3.09 ± 0.83 (***) mm higher in patients of the group good result and also L (**) and C_p (*) are significantly less dysplastic in this group On

TABLL 36

Comparison of measured results for luxating knees which at re examination we classified as good' on one hand and fair" or poor' on the other (see text)
Mean values for females

Col	3	4	5	6	7 (3–5)	8 (4–6)
	Luxating knees classified at re-examination as good		Luxating knees classified at re-examination as fair or poor		Diff good — fair or poor	
	dx (2.)	sin (28)	dx (28)	sin (21)	dx	sin
l	7 60 ± > 0 19	6 39 ± 0 44	7 39 ± > 0 19	4 76 ± 0 59	0 21 ± > 0 30	1 63 ± 0 74
m	3 32 ± 0 34	3 68 ± 0 45	3 96 ± 0 38	3 91 ± 0 45	− 0 64 ± 0 51	− 0 23 ± 0 64
C_p	6 00 ± 1 05	3 86 ± 0 77	4 71 ± 0 63	1 43 ± 0 98	1 29 ± 1 23	2 43 ± 1 2.
I	5 80 ± > 0 38	76 79 ± 0 85	76 07 ± > 0 38	79 86 ± 1 09	− 0 27 ± > 0 57	− 3 07 ± 1.39
I + M	152 52 ± > 0 60	1.3 .5 ± 1 .9	151 64 ± > 0 60	156 67 ± 1 72	0 88 ± > 0 90	− 2 92 ± 2 48

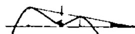
the left side (col 8 Table 37) no significant difference exists with the exception of C_p the magnitudes go in the same direction as on the right side but do not reach the significance limits

C Summary

Those knee joints in which dislocation of the patella laterally has occurred at least twice have at the follow up investigation been classified into three groups (good fair and poor result) primarily according to the subjective troubles in the *femoro patellar joint* of the patient For operated knee joints to be appraised in this prognosis investigation an observation period of more than two years (average for 107 operated knee joints about 10 years) was required For non operated knee joints an illness period of more than five years was required (average for 52 knee joints about 20 years)

TABLE 37

Same as Table 36
Mean values for males



Col	3	4	5	6	(3–5)	8 (4–6)
	Luxating knees classified at re-examination as "good"		Luxating knees classified at re-examination as "fair" or "poor"		Diff "good — fair or poor"	
	dx (17)	sin (1)	dx (17)	sin (10)	dx	sin
l	9 00±0 54		5 91±0 63		3 09±0 83 *	
		8 00±0 49		7 30±0 88		0 0±1 01
m	4 82±>0 16		4 83±>0 16		−0 01±>0 24	
		5 30±0 53		4 70±0 61		0 60±0 81
C_p	4 88±0 72		1 75±1 12		3 13±1 33*	
		3 25±>0 30		3 50±>0 30		−0 25±>0 45
L	73 88±0 98		78 42±1 27		−4 54±1 60 *	
		75 59±0 89		76 30±1 84		−0 71±2 04
L+M	149 41±2 17		152 16±2 85		−2 75±3.58	
		149 18±1 69		151 30±2 32		−2 12±2 83

The classification of the patient material is shown in Table 33

Of 159 dislocating knees 87 (=55 per cent) have obtained a good function in the femoro patellar joint 14 (=9 per cent) of them without operation

The measurement on the x ray pictures showed statistically probable differences on the left side for females and significant differences on the right side for males and uncertain differences on the right side for females and on the left side for males the group classified good result was in some respects less dysplastic than the combined group fair+poor result

Conclusions and summary

A. X-ray examination of the distal femur end

At recurrent dislocation of the patella so-called axial pictures are usually taken of the patella. Because dislocation occurs as a rule when the patella is in the cranial part of the intercondylar groove, one should try to get a picture of this area and not of the caudal parts of the groove. The projection recommended by Knutsson fills this requirement. Small changes in the rotation of the femur and the position of the cassette, however, have consequences for the picture of the formation of the femur condyles; therefore these details should if possible be standardized. The modification of Knutsson's method (described by Furmeier) of keeping the patient's knee joints and foot joints together and x-raying both knee joints at the same time increases the possibility of symmetric position and is recommended as a clinical routine method.

In order to investigate the femoral dysplasia the present author has worked out a method of examining roentgenologically the distal femur end in standardized conditions, and has thereby made it possible to get objective measurable expressions for changes in the shape of the intercondylar groove. With this method two almost simultaneous pictures are obtained, one of the *ventral* area of the femur condyle section on *both* knees, and the other of the *dorsal* area. The ventral picture has the same angle between the roentgen rays and the femur shaft as Knutsson—Furmeier have indicated. On both pictures a horizontal line is projected.

On the *ventral* x-ray picture certain magnitudes were measured: a) the height of the lateral and the medial condyle above the sulcus bottom, b) the angles between the vertical line from the sulcus bottom and lines from the sulcus bottom to the highest point of each condyle, and c) finally the angle between a line through these two highest points and the horizontal line through the sulcus bottom (see Fig. 22).

These magnitudes give an idea of the formation of the osseous parts of the *ventral* condyle section

On the *dorsal* picture the following have been measured a) the distance between the projected horizontal line and the most dorsally lying point on each condyle b) the angle between a line through these two points and that horizontal line which touches the most dorsally lying condyle

These magnitudes give an idea of the torsion rotation conditions and a possibility of estimating approximately the ventro dorsal extension of the condyles

At the appraisal of the femoral dysplasia on pictures taken according to Knutsson—Fürmeier it is better to start from the sulcus angle L+M (see Fig 22) because this angle gives a more definite idea of the femoral dysplasia than does the usual estimation of the height of the lateral condyle above a horizontal line through the sulcus bottom L+M is independent of photographic enlargement and (within reasonable limits) of the rotation torsion of the femur

B Normal material

The author personally investigated 100 females and 100 males with subjectively healthy knees using the method referred to above The measured results are reported in Table 3 p 82

The total sulcus angle L+M shows the following values

	dx	sin
Females	141 79±0 60	142 36±0 61
Males	142 78±0 51	141 90±0 54

A statistically significant difference is usually found between the right and the left side because the distal femur end on the left side stands outwards rotated or outwards torqued in relation to the right side

The female distal femur end is more gracile than the male but is primarily of the same form

C Patient material

131 patients from the south of Sweden and from Copenhagen (81 females and 50 males) with recurrent dislocation of the patella (at least two dislocations) were investigated clinically and roentgenologically by

the author personally and the same magnitudes as in the normal material were measured. The patients were grouped according to certain clinical and anamnestic criteria and the means of the measured magnitudes of each group were calculated and compared with the means of the normal material and other patient groups.

The following appears from the investigation of the patient material.

1. *Rotation torsion.* Common to all groups: no statistically significant difference in rotation or torsion is found between the normal material and the patient material (Table 8). In patients with recurrent dislocation of patella the changes recorded in the ventral parts of the condyle section are thus real and are not due to changed position in the distal femur end, as has been maintained by several authors.

2. *Right left.* The assymmetry established in the normal material between the right side and the left is also found in the measured results in the patient material because the left distal femur end stands more outwards rotated or outwards torqued than the right.

48 patients had bilateral dislocations, 44 had unilateral right, and 38 had unilateral left (82 unilateral dislocations). In the 18 bilaterally dislocating patients the onset of the condition occurred in the left knee twice as often as in the right, and the left knee being that which twice as often gave most symptoms.

3. *The dislocating knee.* Measurement on the x-ray pictures showed pronounced femoral dysplasia in the dislocating knee joints because the height of the lateral condyle as well as the medial above the sulcus bottom is less in dislocating knees and the sulcus angle I+M has increased. This dysplasia in the dislocating knee is more pronounced if the dislocation is bilateral than if it is unilateral but the difference is statistically non significant.

4. *The non dislocating knee.* Of the 82 unilaterally dislocating patients 30 (37 %) had subjective troubles in the form of feelings of instability in the non dislocating knee—only 52 were completely trouble free.

In these unilaterally dislocating patients the *non dislocating knee* also shows statistically significant differences compared with the normal material in the form of lowered condyle heights and increased sulcus angle. This difference is also seen if the values are calculated for

solely the 52 unilaterally dislocating patients who were completely trouble free in the non dislocating knee

The predisposition of the condition is thus bilateral to a considerably larger extent than the clinical manifestation would lead one to believe. This also argues strongly against the suggestion that the low lateral condyle or the increased sulcus angle is secondary and the consequence of the dislocation

5 *The height of the sulcus bottom* The possibility that these dysplastic changes are due to a relative raising of the sulcus bottom rather than to a substantial decrease of the ventro dorsal extension of the condyles is discussed. Certain measured findings argue for this possibility

6 *The age factor* The female patients have their first dislocation on average at age 15.2 years the male at age 16.3 years. Patients whose condition had an earlier onset (females less than 16 years males less than 17 years) have a more pronounced femoral dysplasia than those whose onset came after the mentioned age

7 *Family occurrence* Twenty two females and ten males (32 patients =24 %) stated that some close relative had suffered recurrent dislocation of the patella. The 22 females with positive family anamnesis showed somewhat more pronounced dysplasia than did the other patients but the difference is statistically non significant

The male group is too small for any conclusions to be drawn

No significant difference between patients with and those without positive family anamnesis could thus be demonstrated

8 *Trauma* Five females and 13 males (18 patients) reported a strong and direct assault on the knee as reason for the first dislocation. Of these only one female and six males were unilateral dislocating and with no troubles in the other knee and without family anamnesis. All six males had dysplastic changes in *both* knee joints. Only the female patient showed no signs of dysplasia. This bilateral dysplasia in the males argues for the dysplasia not being secondary but existing before the dislocation and together with the trauma leading to dislocation

9 *Dislocation frequency* No definite relation between the degree of femoral dysplasia and dislocation frequency emerged

10 *Prognosis* The conservatively treated knee joints that showed dislocation for more than five years and the surgically treated knee joints that had an observation period of at least two years were appraised with regard to the condition in the femoro patellar joint

Of 159 dislocated knees appraised in this manner 87 were referred to the group good of whom 14 were without operation On the x ray pictures the group good showed less pronounced dysplasia than did the combined group fair and poor but the differences were only partly significant

Acknowledgements

My grateful thanks are due to Professor Gunnar Wiberg who made this investigation possible by generously placing the resources of the Clinic at my disposal for discussions and invaluable criticism during the progress of the work

To Laborator O Norman head of the Roentgen Diagnostic Clinic II Lund for constructive criticism and for generous help by placing the technical resources of his Clinic at my disposal

To head physician P Thestrup Andersen Copenhagen whose willingness to assist and enthusiasm for the investigation were invaluable and stimulating

To Professor C H Hjortsjö Lund for kind interest and advice in planning the investigation

To head physician Ingemar Bergstrand Boden for his interest good advice and fruitful discussions

To head physician R Schalimtzek—and through him to the Directors and staff of the Ortopedisk Hospital in Copenhagen—for the kind assistance I was given in Copenhagen

To Professor A Bertelsen (Copenhagen) and head physicians M Brunk (Kristianstad) E Hjalmar Larsen (Copenhagen) S v Rosen (Malmo) and K Stenport (Halsingborg) for putting their patient material at my disposal

Economic support was provided by the Medical Faculty of the University of Lund by the Järnhardts Stiftelse and by the Österlunds Stiftelse

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ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM 63

THE LEG AMPUTEE

A CLINICAL FOLLOW-UP STUDY

BY

JAN HANSSON

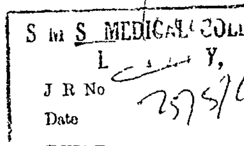
ACTA ORTHOPAEDICA SCANDINAVICA
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From the Orthopædic Department University of Gothenburg
Head Professor Carl Hirsch

Translated by
Claes Magnus Lindskog

Statistics
Lennart Råde

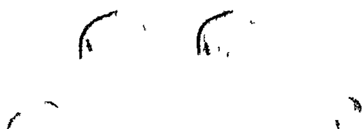
Printed in Sweden
ORSTADIUS BOKTRYCKERI AKTIEBOLAG
GÖTEBORG 1964

Contents

Preface

Amputation is a mutilating and permanently disabling intervention after which rehabilitation is required to help the patient find his place in the world In planning what measures are likely to be most effective for the rehabilitation of leg amputees it is important to know the magni tude of the patient s handicap as a result of the amputation

Against this background the present investigation was designed to provide information on annual frequencies of leg amputees in a Swedish urban population in the past at present and in the future on amputation rates on causes of amputation on postoperative mortality and survival time and on the clinical and sociomedical function of patients various lengths of time after amputation at different ages



CHAPTER 1

Introduction

Pilot study

The initial step in this study was to chart what medical and sociomedical problems were likely to arise in an investigation of the clinical fate of leg amputees These problems were surveyed by studying those 968 patients who had been fitted with prostheses in the Orthopaedic Department at Gothenburg over the years 1912—1956 This period was chosen because the Orthopaedic Department moved to its present premises in 1912 and it was desired to have an observation period of at least 5 years up to 1961, the year this preliminary assessment was carried out Addresses were obtained from the Orthopaedic Department and the Workshop The patients were interviewed by letter

The result of this poll was that 607 patients or 63 per cent were contacted 290 patients or 30 per cent had died and 71 patients or 7 per cent could not be traced Of the 968 amputees the majority — 748 or 77 per cent — were men While the annual number of leg-amputees fitted with prostheses remained substantially constant before 1920, it then rose steadily until 1956 Thus in the quinquennium 1926—1930 the Workshop had 64 patients referred to it and in the period 1951—1955 the corresponding number was 243

In this series of 968 patients the amputation causes — as judged from case notes replies to letters, statements by relatives and information from Public Register Offices — were distributed as follows accidents in 488 patients or 50 per cent peripheral vascular disease in 241 patients or 25 per cent infections in 109 patients or 11 per cent tumours in 75 patients or 8 per cent and miscellaneous causes in 65 patients or 7 per cent

The relative proportions of the amputation causes among the prosthesis equipped patients changed during the period of observation accidents became less and peripheral vascular disease more dominant Of all patients fitted with prostheses traumatic amputees constituted 67 per cent in 1926—1930 and 29 per cent in 1951—1955, the corresponding figures

for gangrene amputees being 2 per cent and 57 per cent As from 1951 peripheral vascular disease was the largest aetiological group among these prosthesis equipped amputees and before that year accidents were in majority

Few conclusions could be drawn from the aforementioned figures Most of the patients had been referred to the Workshop from a region that had changed in size during the period of observation The age structure of the population had altered, a factor probably contributing to the increased proportion of gangrene amputees The medical profession has acquired a more active attitude toward elderly patients causing rising numbers of them to be referred for prosthesis fitting The amputee s economic status has improved and grants have been introduced to defray the costs of prostheses as a result the proportion of amputees fitted with prostheses has grown

This postal interview study provided no information on the annual number of leg amputees or on the fate of those that had not been fitted with prostheses

To answer those questions which had been left open by the pilot investigation it was necessary to carry out additional studies and to fix the meaning of various concepts

Definitions

Leg-Amputee a patient whose lower extremity has been amputated proximal to the ankle joint

Amputation Year the calender year when the patient underwent the first amputation proximal to the ankle joint

Amputation Age the patient s age at the time of the first amputation *proximal to the ankle joint*

Amputation Cause the main disease or trauma that gives rise to a condition necessitating amputation For example the main disease is peripheral obliterative arteriosclerosis which leads to a condition, gangrene, which in turn calls for amputation The amputation cause in this example is peripheral obliterative arteriosclerosis

Postoperative Complications complications occurring during the six months following the first amputation proximal to the ankle joint

Duration of Treatment the length of time elapsed from the day the patient was admitted to hospital to the day he was discharged

Amputation Level denoting that the leg was amputated either below or above the knee Patients whose hip or knee joint had been exarticulated were regarded as above knee amputees

Survival Time the time from the last amputation proximal to the ankle joint to the day of death

Prosthesis-Walker a patient who unaided by another person has used his prosthesis daily for six months, with or without supporting himself on a cane

Clinical Function in this context merely the patient s ability to use his prosthesis

Sociomedical Function the patient s ability to benefit from his clinical function in daily life

CHAPTER 2

Methods

A list was prepared of all the 586 inhabitants of Gothenburg who had undergone leg amputations in Gothenburg over the years 1947 through 1962 Primary information was obtained from the operation schedules for the following departments Departments of General Surgery I and II Extremital Surgery, Thoracic Surgery and Orthopaedics, all in Sahlgrenska Sjukhuset, and the Surgical Clinics of the Paediatric Hospital Ekmanska Sjukhuset and Carlanderska Sjukhemmet This group of 586 leg-amputees will hereinafter be known as the 586-Series

Occasionally supplementary data were extracted from case records The information thus gathered made it possible to analyze the frequencies as well as the age and sex distributions of these leg-amputees These results are presented in Chapters 4 and 7

For further analysis personal contact was sought with the amputees It was desirable to have a long observation period to enable studies of the patient s ability to adapt himself to his handicap It was necessary to establish whether the leg-amputee s clinical and socio-medical function had improved

Accordingly conditions for new leg-amputees in Gothenburg during the years 1947 through 1956 and 1961 were further scrutinized This part of the investigation was commenced in 1961 and concluded the 28th February 1963 These 331 leg-amputees will hereinafter be known as the 331-Series The decade 1947—1956 was chosen in order to have a substantial number of patients with an observation period of at least five years, and 1961 was included for statistical reasons because a large number of leg amputations were performed in that year The observation period for the latter patients was at least one year Among the patients in the 331-Series 84 were alive all of whom were followed up by the writer with respect to the points included in the form reproduced as Fig 2 1 Observation periods for these 84 patients will be found in Table 2 1 Of these 84 patients 50 were seen in the Orthopædic Department, 13 in their homes

Date

Telephone No

Name Address

1–3 Identity No
4–5 Date of birth
6–7 Year of amputation
8 Clinic or hospital where amputation was done
9–10 Age at amputation
11–12 Current age
13 Cause of amputation
14 Amputation level
15 Leg amputated
16 Sex
17 Postoperative complications
18 Type of prosthesis
19 No of prosthesis changes
20 Years since first prosthesis fitted
21 Distress from prosthesis
22 Vocation or trade before amputation
23 Vocation or trade after amputation
24 Degree of disablement — Pension
25 Car ownership — Economy
26 Institutional care
27 Intercurrent disabling diseases
28 General health
29 Gait ability to walk
30 Condition of stump
31 Stump length
32 Phantom pains
33 Distress from stump
34 Knee/hip joint condition
35 Practical function
36 Working capacity

Fig 2 1 Form used for follow up investigation

Table 2 1 Duration of amputation for 84 followed up patients in the 331 Series

Duration of amputation years	No
1–2	31
5	10
6–10	24
11–15	19

Table 2 2 Number of amputees and duration of amputation in the 133 Series

Duration of amputation years	Age at amputation						Total
	-9	10-19	20-29	30-39	40-49	50-59	
< 11	2	1	6	3	4	6	22
11-20	1	8	11	11	2	2	35
21-30	2	9	7	4	3	1	26
31-40	2	8	8	4	3	0	25
> 40	5	14	5	1	0	0	25
Total	12	40	37	23	12	9	133

and 21 in various institutions in which they were staying An additional patient — a 13 years old traumatic amputee in 1949 — was regarded as alive but not followed up owing to emigration

All the 246 other patients had died Their fate was as far as possible followed from the day of the amputation to the day of death After dis charge from the Surgical Department many of them had been admitted to a Department for Chronics, and available case records were studied Records of the Orthopaedic Workshop were perused with respect to those who had been fitted with prostheses Relatives as well were occasionally interviewed Causes of death were ascertained from autopsy reports and Public Register Offices

Analysis of the data for the 331-Series produced information on ampu tation causes, postoperative course, survival time, clinical function and sociomedical function Results are presented in Chapters 5 6, 7, 8 and 9

Owing to the heavy preponderance of elderly leg amputees in the 331-Series, it did not adequately portray the clinical and sociomedical functions of young leg-amputees Hence the investigation was supplemented by personal follow up examinations in the Orthopædic Department of 133 patients, namely all leg amputees before 1957 with amputation ages below 60 years who had been fitted with prostheses in the Workshop at Gothen burg and in 1961 were domiciled in Greater Gothenburg (Gothenburg, Kungälv, Kungsbacka, Molndal, Savedalen, Partille) Observation periods versus decades of amputation age are given in Table 2 2 The patients were traced with the aid of information supplied by the Orthopædic Workshop, the examination comprising the items shown in Fig 2 1 This group of patients — hereinafter known as the 133 Series — were characterized by long survival times The observation period was in no case less than five years The data for the 133 Series cast light upon the clinical

and sociomedical functions of patients who have undergone amputation and been equipped with prostheses at an active age The results are pre sented in Chapters 8 and 9

As 31 patients were common to the 133 Series and 331-Series altogether 186 leg amputees were examined by the writer personally

Thus three series of patients were studied *viz*

(i) The 586 Series comprising all Gothenburg residents subjected to leg amputation in Gothenburg in 1947 through 1962

(ii) The 331 Series comprising all Gothenburg residents subjected to leg amputation in Gothenburg in 1947 through 1956 and 1961

(iii) The 133 Series comprising all Gothenburg residents subjected to leg amputation in Gothenburg before 1957 with amputation ages below 60 years and prosthesis equipped at the Orthopædic Work shop in Gothenburg who were domiciled in Greater Gothenburg in 1961

Thus as dictated by the necessity of obtaining data suitable for statistical analysis the investigation embraced different groups of patients for which the observation periods ages and durations of prosthesis use varied

Statistical Methods

Standard statistical methods were used for graphical and numerical description of the statistics collected in the present investigation Simple statistical predictions were sometimes made in connection with census figures χ^2 methods were used extensively both regular χ^2 techniques for analysis of qualitative data (cf Maxwell 1961) and partition of χ^2 for studying variation within and between sets Some medical phenomena influenced by a complex network of factors were analyzed in the form of a 2^n contingency table the observed proportion then being transformed by the logit transformation $z = \ln \frac{p}{1-p}$ and analysis of variance by the method due to Yates This method not only enables factors of significance to be extracted but also supplies information on interaction between factors Unless otherwise specified differences were significant on the 5 per cent level or better

Reference Maxwell A E Analyzing Qualitative Data Methuen & Co Ltd London 1961

CHAPTER 3

Clinical Material

Several clinical investigations of amputees and their problems have been published since 1950 (McKenzie, 1953, Gingras *et al*, 1954, Jansen, 1960 *Hirsch, 1961 Wolters, 1961 Bugel & Carlsson 1961*, Widolf, *1961*, Alffram & Holmquist, 1961 Fellander Hallberg & Storck, 1962, Lempke *et al*, 1963) Some of the series are surveyed in Table 3 1 Many of these publications come from rehabilitation clinics or prosthesis and amputation centres The main aim of Swedish investigations in the 1960 s has been to evaluate the effectiveness of rehabilitating measures taken at various orthopædic clinics (Hirsch, 1961, Widolf 1961, Alffram & Holmquist, 1961 Fellander, Hallberg & Storck, 1962 Lundholm, 1963)

In numerous investigations there has been a considerable preponderance of patients over 60 years old This applies to the British report just mentioned, as well as to Alffram & Holmquist (1961), Fellander, Hallberg & Storck (1962) and Lundholm (1963)

Most papers on leg-amputees have dealt with a majority of men The magnitude of the masculine dominance has varied with the age distribution of the patients Series of mainly geriatric patients exhibit small sex differences For example Alffram & Holmquist had 53 per cent men and Lund holm 54 per cent men Series of younger amputees include a greater preponderance of men (Jansen 1960, Hirsch, 1961, Widolf 1961)

The 586 Series

The numbers of leg amputees in Gothenburg for each of the years 1947 through 1962 are plotted in Fig 3 1 It will be seen that the annual number of amputees rose from 1955 While 21 patients underwent leg amputation in 1954, the corresponding figure in 1955 was 38 and in 1962 it was 69 The age distribution of the 586 Series is shown in Fig 3 2 In conformity with Gothenburg population statistics for recent years the amputation age was divided into the decades —9 years, 10—19 years

Table 3 1 Number of amputees observation periods and amputation causes in recent publications

Authors and year	Observation period	No	Amputation causes in per cent			
			Peripheral vascular disease	Accidents	Tumours	Miscellaneous
Gingras *et al* Montreal, Canada 1954	1949–53	90	61	21	4	14
Jansen Copenhagen Denmark 1960	no details	669	56	29	5	10
Annual Report England 1961	1960	2256	63	23	8	6
Widolf Lund Sweden 1961	1949–58	134	49	16	24	11
Bugel & Carlsson Nashville Tennessee U S A 1961	1947–60	222	56	38	5	1
Alffram & Holmquist Malmo Sweden 1961	1949–58	149	84	10	5	1
Dale & Jacobs Nashville Tennessee U S A 1962	1956–60	385	62	16	6	16
Fellander *et al* Stockholm Sweden 1962	1954 1957	87	86	7	6	1
Lundholm Karlstad Sweden 1963	1951–60	93	85	no details	no details	no details
586-Series Gothenburg 1964	1947–62	586	85	9	4	2

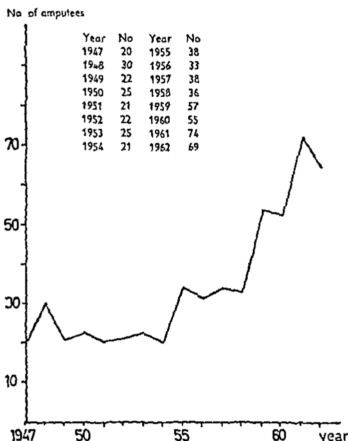


Fig 3 1 Frequency of leg amputees in Gotehnburg 1947—1962

20—29 years, etc The amputation age of most patients exceeded 60 years, the largest age group being the 70—79 year olds In the 586 Series 82 per cent of the patients were over 60 years of age at the amputation

The 586 Series included 347 men or 59 per cent

The distribution of amputation causes is portrayed by Fig 3 3 Peripheral vascular disease was responsible for as much as 85 per cent of all the amputations, accidents for 9 per cent and all other causes for 6 per cent

Being part of the 586-Series the 331-Series is covered by the aforementioned tables and diagrams and needs no separate presentation

The 133 Series

Most of the patients domiciled within Greater Gothenburg in 1961 whose amputation age was less than 60 years had been operated on in the years immediately preceding 1956 (cf Table 3 2) No amputation had

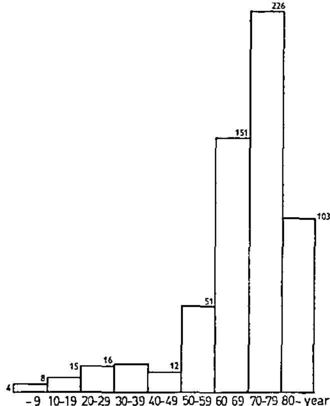


Fig 3 2 Age at amputation in Gothenburg 1947—1962

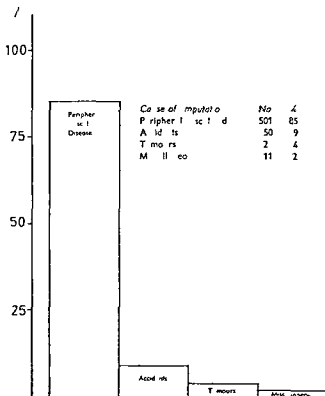


Fig 3 3 Causes of amputation in Gothenburg 1947—1962

Table 3 2 Year of amputation related to age in the 133 Series

Year	Age at amputation						Total
	–9	10–19	20–29	30–39	40–49	50–59	
–1919	4	9	5	0	0	0	18
1920–29	3	12	8	4	2	0	29
1930–39	2	9	4	5	2	0	22
1940–49	1	5	12	8	3	2	31
1950–56	2	5	8	6	5	7	33
Total	12	40	37	23	12	9	133

been performed before 1919 on any patient who was then over 29 years old The next two age groups 1920—1929 and 1930—1939 included amputees with amputation ages up to 49 years The patients in the period 1940—1956 were of all ages up to 60 years The comparatively few amputees in the first period is accounted for by death of subjects older than 30 years at amputation prior to 1919

The distribution of the 133 Series in amputation age groups of 10 years is shown in Table 3 3 The largest group, comprising 40 patients or 30 per cent had amputation ages between 10 and 19 years As many as 112 patients or 84 per cent of the whole series had amputation ages below 40 years This great preponderance of patients with amputation ages up to 39 years is due to the high incidence of accidents at these ages The amputation age group of 50—59 years included merely 9 patients

The 133-Series comprised many more men than women, namely 107 or 80 per cent and 26 or 20 per cent respectively This should be considered in the light of the high frequency of acidents among men

The distribution of amputation causes in the 133 Series is shown in Table 3 4 Accidents constituted the largest group with 82 patients or 62 per cent The majority of accidents took place in traffic, this group comprising 39 patients The second largest group comprised industrial accidents excluding traffic accidents with 25 patients (see Table 3 5) Tram and railway accidents were responsible for 20 male and 1 female amputees

Below knee amputees, including bilateral below knee amputees numbered 83 the remaining 50 patients being above knee amputees Seven patients were bilateral amputees all of them below-knee

Table 3 3 Age at amputation for men and women in the 133-Series

Age at amputation years	Men	Women	Total
— 9	8	4	12
10—19	29	11	40
20—29	35	2	37
30—39	20	3	23
40—49	9	3	12
50—59	6	3	9
Total	107	26	133

Table 3 4 Causes of amputation for men and women according to age in the 133 Series

Cause of amputation	—9		10—19		20—29		30—39		40—49		50—59		Total	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Congenital deformities	4	2	1	2	0	0	0	1	0	1	0	0	5	6
Infections	1	0	2	2	8	0	2	1	1	0	0	1	14	4
Accidents	3	2	23	3	25	0	14	1	5	2	4	0	74	8
Tumours	0	0	3	3	1	1	2	0	1	0	0	2	7	6
Miscellaneous	0	0	0	1	1	1	2	0	2	0	2	0	7	2
Total	8	4	29	11	35	2	20	3	9	3	6	3	107	26

Table 3 5 Types of accidents sustained by men and women in the 133 Series

Type of accident	Men	Women	Total
Tram and railway	20	1	21
Motorcycle and car	14	4	18
Military	8	0	8
Industrial	24	1	25
Others	8	2	10
Total	74	8	82

CHAPTER 4

Frequency, Sex and Age of Leg-Amputees

Frequencies

The amputation rate varies widely in the few studies published Russek (1961) stated that the leg amputee population of the U S A was some 700 000 and estimated that approximately 35,000 new amputations were performed every year

Some information on the frequency of amputations in England and Wales for 1960 has been published by the British Ministry of Health The estimated annual frequency of arm and leg amputees in the gross population was 1 13 000 the ratio of leg amputees to arm amputees being approximately 10 1 In that year 2256 new leg-amputees were treated at all Prosthetic Centres, an 8 per cent increase on the figure for 1959

Jansen (1960) calculated the approximate amputation rate to be 0 1—0 5 per cent

Alffram & Holmquist (1961) reported that in the decade 1949—1958 leg amputations were performed on 149 inhabitants of Malmo city, which in 1955 had a population of 210,000 The annual leg amputation rate during the period studied by these workers was about 1 14,000 They predicted that the leg-amputee population of Malmo would be 50 per cent higher in 1970 than in 1955 provided the indications for amputation remained unchanged Fellander, Hallberg & Storck (1962) reported that the total number of Stockholm patients undergoing amputation was 45 in 1954 and 42 in 1957 3 arm amputees being included in these figures Hence the annual amputation rate in Stockholm would be about 1 18,000

Amputations were performed at eight clinics in Gothenburg during the years 1947—1962 the patients being distributed by clinics as shown in Table 4 1 The proportion of legs amputated in the departments of general surgery was 89 per cent and the number of operating surgeons

exceeded 100 Hence there could have been no bias either in indications for amputation or in surgical technique

Annual frequencies of new amputees in different age groups are set out in Table 4 2

Table 4 1 The 586-Series classified according to departments performing the amputation

Surgical department hospital	No of amputees
Surgical department I & II Sahlgrenska hospital	441
Ekmanska hospital	[illegible]
Department of surgery for trauma	36
Orthopaedic department	19
Paediatric hospital	7
Carlanderska hospital	5
Thoracic surgery department	1
Total	586

Table 4.2. Age and sex distribution of the 586-Series

Year	0–9		10 19		20–29		30–39		40–49		50–59		60–69		70–79		80–89		Total	Total
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1947	0	0	0	0	1	0	1	1	1	0	1	1	3	2	4	2	1	2	12	8
1948	1	0	1	0	1	1	1	0	0	0	4	3	5	3	4	3	1	2	18	12
1949	0	0	2	0	2	0	0	0	0	1	2	0	2	1	3	6	1	2	12	10
1950	0	0	0	0	1	0	3	0	0	0	1	1	1	6	4	5	2	1	12	13
1951	0	0	0	1	1	0	2	0	0	0	2	1	3	3	2	5	0	1	10	11
1952	0	0	0	0	0	0	1	0	1	1	1	0	7	3	4	2	1	1	15	[illegible]
1953	0	0	1	0	0	0	2	0	1	0	4	0	4	5	4	2	1	1	17	8
1954	0	0	0	0	0	0	0	0	0	0	1	2	2	3	3	4	5	1	11	10
1955	2	0	0	1	0	1	1	1	0	0	2	1	7	3	8	9	0	2	20	18
1956	0	0	0	0	0	0	0	0	2	0	3	0	4	4	9	6	2	3	20	13
1957	0	0	0	0	2	0	0	0	0	0	3	1	4	3	8	8	4	5	21	17
1958	0	0	1	0	1	0	0	0	0	0	0	0	5	4	9	8	6	2	22	14
1959	0	0	0	0	2	0	2	0	2	0	2	0	13	3	11	11	5	6	37	20
1960	1	0	0	0	0	0	1	0	1	0	4	0	6	4	11	13	6	8	30	25
1961	0	0	0	0	1	0	0	0	1	0	7	1	16	5	12	11	9	11	46	28
1962	0	0	1	0	1	0	0	0	1	0	1	2	11	6	21	14	6	5	42	27
Total	4	0	6	2	13	2	14	2	10	2	38	13	93	58	117	109	50	53	345	241
Percentage	0 7	0 0	1 0	0 3	2 2	0.3	2.4	0.3	1 7	0.3	6 5	2	15 9	9 9	20 0	18 6	8 5	9 0	58 8	[illegible]

Table 4 3 Male and female populations over 60 and total population over and under 60 years in Gothenburg 1947—1962

Year	Men > 60 year	Women > 60 year	Total population > 60 year	Total population < 60 year
1947	17860	23165	41025	292247
1948	18628	24089	42717	301261
1949	19429	25050	44479	304666
1950	20265	26044	46309	307378
1951	21029	26875	47904	310290
1952	21822	27732	49554	313446
1953	22645	28617	51262	316317
1954	23499	29530	53029	320404
1955	24381	30476	54857	325585
1956	25045	31470	56515	330546
1957	25727	32496	58223	334354
1958	26427	33555	59982	337223
1959	27146	34649	61795	338992
1960	27885	35776	63661	341591
1961	28644	36942	65586	342706
1962	29424	38146	67570	343321

An amputation age of 60 years was chosen in order to find out if the age shift which has taken place in the gross population was manifested in the amputation frequencies

Data on the population of Gothenburg in 1947—1962 (Table 4 3) were taken from Statistisk Årsbok for Goteborg (Statistical Yearbook for Gothenburg) The annual amputation rates are expressed as the observed number of new amputees per 100 000 inhabitants (Table 4 4)

Scrutiny of the annual rates compiled in Table 4 4 reveals that the amputation rate remained substantially constant up to 1954, whereupon it began to rise for patients over 60 years of age Notably as compared with the amputation rate for 1947, that for 1962 was 2 8 times higher for all leg-amputees 2 9 times higher for men over 60 years old and 2 5 times higher for women over 60 years old In other words, an increased amputation rate was observed, predominantly in the period 1955—1962, which mainly affected men over 60 years old

Table 4 5 reveals how the amputation rate rose with age for the amputees older than 60 years and also that it tended to rise within age groups over the years surveyed Some years had to be omitted because

Table 4 4 Observed amputation rates per 100 000 inhabitants for the entire population for all men and women for the entire population over and under 60 years and for men and women over 60 in Gothenburg 1947—1962

Year	Total under 60	Total over 60	Men over 60	Women over 60	All men	All women	Total
1947	2.1	34.1	44.8	25.9	7.5	4.6	6.0
1948	4.0	42.1	53.7	33.2	10.8	6.7	8.7
1949	2.3	33.7	30.9	35.9	7.1	5.6	6.3
1950	2.0	41.0	34.5	46.1	7.0	7.1	7.1
1951	2.3	29.2	23.8	33.5	5.8	6.0	5.9
1952	1.3	36.3	55.0	21.6	8.5	3.7	6.1
1953	2.5	33.2	39.7	28.0	9.5	4.2	6.8
1954	0.9	33.9	42.6	27.1	6.1	5.2	5.6
1955	2.8	52.9	61.5	45.9	10.8	9.2	10.0
1956	1.5	49.5	59.9	41.3	10.6	6.5	8.5
1957	1.8	55.0	62.2	49.2	11.0	8.5	9.7
1958	0.6	56.7	75.7	41.7	11.3	6.9	9.1
1959	2.4	79.3	106.8	57.7	18.9	9.8	14.2
1960	2.0	75.4	82.5	69.9	15	12.0	13.6
1961	2.9	97.6	129.2	73.1	23.1	13.4	18.1
1962	1.7	93.2	129.1	65.5	20.9	12.9	16.8

exact figures are not available for the size of Gothenburg s population in the years 1947—1949 1951—1954 and 1959 The mean amputation rate during the years shown in Table 4 5 was about 1 2800 in the 60—69 years amputation age group around 1 900 in the 70—79 years group and approximately 1 500 in the 80—89 years group

The average amputation frequency in the present investigation was around 1 10 000 On this basis the estimated rate for 1947 would be about 1 16 000 and for 1962 approximately 1 6000 This implies that the amputation rate underwent considerable variations from year to year

Amputation rate variations are shown in Fig 4 1 Evidently the rate lay fairly constant in the years 1947—1954 but rose sharply in subsequent years The lowest curve discloses that the amputation rate for subjects under 60 years of age remained unvaryingly low

It has appeared from the foregoing that the number of new amputations rose markedly over the period 1955—1962 For the relative amputation rate defined as the ratio of amputees to the total number of potential amputees has gone up from 0 06 per cent in 1947 to 0 168 per cent in 1962

Year	Observed no of amputees	Mean female population over 60 years old	Expected No of amputees at constant rate
1947—48	14	23627	21
1949—50	21	25547	23
1951—52	15	27304	25
1953—54	16	29074	26
1955—56	27	30973	28
1957—58	30	33026	30
1959—60	45	35213	32
1961—62	52	37544	34
$\chi^2 = 25.52$ d f = 7 $0.005 < P < 0.001$			

Table 4 8 Numbers of amputees observed vs expected at constant rate in the female population over 60 years old in Gothenburg 1947—1962.

Year	Observed no of amputees	Mean male population under 60 years old	Expected No of amputees at constant rate
1947—48	18	296754	12
1949—50	13	306022	13
1951—52	11	311868	13
1953—54	11	318360	13
1955—56	14	328066	13
1957—58	8	335778	14
1959—60	15	340292	14
1961—62	16	343014	14
$\chi^2 = 6.14$ d f = 7 $0.5 < P < 0.6$			

Table 4 9 Numbers of amputees observed vs expected at constant rate in the population under 60 years old in Gothenburg 1947—1962

upon increased sharply To analyze this phenomenon, the χ^2 value found for the entire 586 Series was partitioned into three components measuring respectively, differences within the years 1947—1954, within the years 1955—1962 and between the periods 1947—1954 and 1955—1962 The results are assembled in Table 4 10 which discloses that whereas there was no significant increase in amputation rate within the years 1947—1954, this rate rose markedly within the years 1955—1962 In addition the periods 1947—1954 and 1955—1962 had different amputation rates Hence it is justified to conclude that the amputation rate was constant during the years 1947—1954 but then rose considerably over the years 1955—1962

Table 4.10 χ^2 partitioning between the years 1947—1954 the years 1955—1962 and the periods 1947—1954 and 1955—1962.

Basis for comparison	χ^2	d.f.	P
Between years 1947—54	0.84	3	0.8 < P < 0.9
Between years 1955—62	38.5	3	P < 0.0005
Between periods 1947—54 and 1955—62	56.03	1	P < 0.0005
Total	95.4	7	P < 0.0005

Considering that 82 per cent of the patients in the 586 Series were older than 60 years at amputation while only 17 per cent of Gothenburg's population was over 60 years of age during the period 1947—1962 the observed increase in the amputation rate over 60 years of age during the period 1955—1962 could be wholly due to the progressive shift towards higher ages in the population at large. This might also modify the aforementioned pronounced increase with rising age over 60 years in the leg amputation rate (cf. Table 4.5). To ascertain whether the increased amputation rate was wholly due to the age composition of the population or whether there was a true increase of amputation rate within age groups over 60 years χ^2 analysis was used in the same way as for Tables 4.6, 4.7, 4.8 and 4.9. The observed amputation rate was thus compared with an expected amputation rate based on a constant mean rate for the years 1950, 1955, 1958 and 1960—1962. It turned out that there was not a significantly increased amputation rate among the 60—69 years olds (χ^2 = 7.85, d.f. = 5). On the other hand both the 70—79 year olds (χ^2 = 74.6, d.f. = 5, P<0.001) and the 80—89 year olds (χ^2 = 14.27, d.f. = 5, 0.05>P>0.01) exhibited significantly increased amputation rates.

The amputation rates for men and women must be compared within each 2 year period owing to the observed amputation rate differences between the periods 1947—1954 and 1955—1962. Table 4.11 presents χ^2 values for each 2-year period. It appears that with the exception of 1947—1948 the amputation rate difference between the sexes tended gradually to grow larger. The difference was significant in 1961—1962 (χ^2 = 12.35, d.f. = 1, P<0.001).

Age and Sex

The aforementioned Annual Report from the British Ministry of Health for 1960 stated that the proportion of amputees in the age groups from 0—79 years increased progressively. The 70—79 year olds were the largest

group, representing 23 6 per cent of all the 2256 new cases of leg amputation 65 5 per cent were over 50 years and 51 per cent over 60 years Women formed the minority in all age groups The difference between the sexes was small in the age group 80—89 years which comprised 69 men and 60 women Among all the amputees the ratio of men to women was 2 4 1

In Jansen s (1960) series of 669 leg amputees, 16 per cent were under 20 years old, 47 per cent 20—60 years and 37 per cent over 60 years In his series of amputees 28 per cent were women In Alffram & Holmquist s (1961) series 76 5 per cent of the patients were over 60 years old the ratio of men to women being 1 1 1

Among the patients in the Stockholm series described by Fellander, Hallberg & Storck (1962), 70 per cent were over 60 years old 66 per cent of the amputees were men

Table 4 11 Observed biennial amputation rates for men and women over 60 years old in Gothenburg 1947—1962

Years	Men			Women			χ^2
	Population	No of amputees	Biennial amputation rate per 100 000	Population	No of amputees	Biennial amputation rate per 100 000	
1947—48	18244	18	98 66	23627	14	59 25	2 094
1949—50	19847	13	65 60	25547	21	82 20	0 416
1951—52	21426	17	79 34	27304	15	54 94	1 090
1953—54	23072	19	82 35	29074	16	55 03	1 431
1955—56	24713	30	121 39	30973	27	87 17	1 574
1957—58	26077	36	138 05	33026	30	90 84	2 912
1959—60	27516	52	188 98	35213	45	127 79	3 746
1961—62	29034	75	258 32	37544	52	138 50	12 345

The age and sex distributions of the 586-Series are shown in Table 4 2 (p 21) the age at the primary amputation being specified for bilateral amputees Among the 586 amputees, 82 per cent had amputation ages over 60 years The largest amputation age group was 70—79 years with 39 per cent of the patients At the time of the amputation 9 per cent were less than 50 years old

In most age groups there was a distinct preponderance of men Amputation was 7 times as common among men as among women in the age group 30—39 years With rising age the masculine preponderance diminished and yielded to a preponderance of women in the 80—89 year group This is because of the great preponderance of women in the population over 80 years of age In 1955 the population of Gothenburg included over twice as many women as men at the age of 85 The ratio of men to women in the entire 586 Series was 1 4 1 among amputees under 60 years old 4 1 1 and among amputees over 60 years old 1 2 1

To establish whether a shift towards higher amputation ages was taking place the median and 75th percentile ages were calculated Over the period concerned both the median and 75th percentile ages remained unchanged through 1953 and then showed a weak tendency to rise the median age rising from 65 years in 1953 to 73 years in 1962 (Table 4 12)

A better impression of the amputation age fluctuations was formed by calculating what proportion of all the amputees had been below a given

Table 4 12. Median and 75th percentile ages within years among amputees in Gothenburg 1947–1962.

Year	Median age	75th percentile age
1947	69.0	77.0
1948	64.0	73.0
1949	73.0	78.0
1950	68.0	78.0
1951	68.0	74.0
1952	68.0	74.0
1953	65.0	71.0
1954	72.0	80.0
1955	69.0	74.5
1956	72.0	77.0
1957	75.0	79.5
1958	74.0	79.0
1959	71.0	76.5
1960	74.0	81.0
1961	72.0	80.0
1962	73.0	77.0

CHAPTER 5

Amputation Causes

Pearse & Ziegler (1940) and Conway & Meigher (1942) noted that mostly diabetic gangrene occurred among patients aged 60—70 years Lempke *et al* (1963) found that amputation took place 3 years earlier in diabetic than in non diabetic patients with gangrene Bell (1957) demonstrated that gangrene was 53 times as common in male diabetics as in non diabetic men and 71 times as common in female diabetics as in non diabetic women Dry & Hines (1941) reported that the incidence of peripheral vascular complications of diabetes was twice as high among men as among women Among diabetics referred for prosthesis fitting in England and Wales in 1960 there were equal numbers of men and women

Studying the long-term prognosis in a series of 165 living and 65 deceased diabetics Lundbæck (1953) found no correlation between the frequencies of diabetic nephropathy and gangrene

A series of 46 diabetics with gangrene and infection studied by Conway & Meigher (1942) included 26 receiving insulin and 11 on dietetic treatment while the remaining 9 patients were newly diagnosed diabetics

Diabetes is associated with extensive lesions of the vascular tree as is illustrated by the high proportion of bilateral amputees and circulatory disturbances from other organs encountered among diabetics Joslin (1944) reported that 39 of 100 unilateral amputees with diabetes eventually had to have the remaining leg amputated Silbert (1952) stated that 30 per cent of diabetic amputees had the other leg amputated within three years after the primary amputation and after five years 51 per cent of the survivors were bilateral amputees Bell (1957) found bilateral gangrene in 26 per cent of diabetic amputees and in 21 per cent of non diabetic amputees Claugus *et al* (1958) noted a high frequency of heart disease in patients with gangrene

In McKenzie's (1953) series of 344 British amputees over 65 years of age referred for prosthesis fitting there were three times as many non diabetic as diabetic patients with gangrene Gingras *et al* (1954) observed

a preponderance of diabetics among amputees treated in a rehabilitation centre in Montreal Chapman *et al* (1959) in the USA described a series of 51 elderly amputees a high proportion 45 per cent of whom had arteriosclerotic cardiovascular disease The majority of gangrene amputees treated at prosthetic centres in England and Wales during 1960 were non diabetic In Alffram & Holmquist s (1961) investigation from Sweden diabetics were in majority with 61 patients or 41 per cent of the 149 amputees followed by 41 non diabetics or 27 per cent Most of the gangrene amputees in their series were in the 70—79 year amputation age group Lempke *et al* (1963) found that 39 per cent of 200 obliterative arteriosclerosis amputees suffered from arteriosclerotic cardiac disease

In England and Wales in 1960 industrial accidents were responsible for 32 per cent and traffic accidents for 54 per cent of the amputations among all traumatic amputees Traffic accidents often resulted in injuries to drivers and passengers in motor vehicles The ratio of men to women was 6 3 1 Jansen (1960) in Denmark published an investigation of 669 leg amputees 36 per cent of whom were traumatic In the latter category the injuries were due to traffic accidents in 33 per cent and to industrial accidents in 28 per cent

Classification

The amputation causes in the 331-Series were distributed as shown in Table 5 1 As a rule the leg amputee suffers from some primary disease which has given rise to a secondary condition that has made amputation obligatory The principle adopted in the present investigation was as mentioned to specify the primary disease as the cause of amputation Exceptionally however it may be impossible to distinguish the primary disease Accordingly three cases will now be described and the classification of the amputation cause will be given though it is debatable what should be regarded as the amputation cause

Patient 003 male born July 26 1873 For at least 70 years he had been treated for osteomyelitis with fistulization in the right femur and humerus Operative excavation and sequestrectomy were performed most recently April 23 1951 Pathological examination of the scrapings disclosed squamous carcinoma probably arising from a fistula The leg was amputated above the knee May 30 1951 The wound healed and a prosthesis was fitted and the patient could manage at home with negligible outside assistance Died July 22 1953 in Vasa Sjukhus Cause of death cardiosclerosis pulmonary cancer and prostatic hypertrophy as noted at autopsy In this case the amputation cause was regarded as osteomyelitis which had given rise to secondary cancer

Patient 129 male born May 26 1949 At birth aplastic anaemia was diagnosed and up to 1955 this condition had called for some 70 blood transfusions Admitted January 8 1955 to the Paediatric Hospital s Surgical Ward where splenectomy was performed two

days later Postoperatively the patient developed a shock like condition and a vessel was exposed By misadventure the posterior tibial artery was catheterized The result was gangrene of the foot in turn necessitating amputation below the knee January 27 1955 The wound was debrided and a reamputation performed on respectively February 25 and March 13 1955 The patient was provided with a prosthesis and learned to use it well Died September 19 1956 Cause of death hypoplastic anaemia and acute pharyngitis as noted at autopsy This patient was placed in the accident group

Patient 192 female born August 25 1873 Admitted April 2 1956 to the Surgical Department in a state of complete disorientation with a comminuted fracture of the left lower leg calcaneal traction being applied the same day The 15th April a toe of the left foot exhibited gangrene which progressed so that the leg had to be amputated above the knee May 17 1956 June 1st the patient was transferred to a hospital for chronics where she died December 24 1956 Postoperatively the patient was bed ridden until she died i e 7 months Cause of death generalized arteriosclerosis as verified at autopsy In this case obliterative arteriosclerosis was regarded as the amputation cause

Table 5 1 Distribution of amputation causes among amputees in Gothenburg 1947—1956 and 1961

Amputation cause	No of amputees	Per cent
Arteriosclerosis with diabetes	143	43 2
Arteriosclerosis without diabetes	93	28 1
Accidents	35	10 6
Embolism and thrombosis	25	7 6
Tumours	17	5 1
Buergers disease	5	1 5
Raynauds disease	2	0 6
Congential tibial pseudoarthrosis	2	0 6
Frost bite	2	0 6
Popliteal artery aneurysm	2	0 6
Osteomyelitis	2	0 6
Chronic leg ulcer	1	0 3
Vascular disease	1	0.3
Syphilitic arteritis	1	0.3
Total	331	100 0

Obliterative Arteriosclerosis With Diabetes

Of the patients in the 331-Series 143 or 43 per cent had diagnosed diabetes mellitus 85 per cent of these diabetics had been under treatment for more than a year before the amputation was performed Quantitative

Table 5 2. The diagnosis and sex ratio in amputees of various ages

Causes of amputation	No	Men / Women	Amputation age 0—49	50—59	60—69	70—79	80—89
Arteriosclerosis with diabetes	143	$\frac{73}{70} = 1.0$	1	12	59	62	9
Arteriosclerosis without diabetes	93	$\frac{55}{38} = 1.4$	0	4	21	33	35
Accidents	35	$\frac{30}{5} = 6.0$	22	8	1	3	1
Embolism and thrombosis	25	$\frac{14}{11} = 1.3$	0	4	6	10	5
Tumours	14	$\frac{6}{8} = 0.8$	10	1	1	2	0
Miscellaneous	21	$\frac{15}{6} = 2.$	6	9	3	3	0
Total	331	$\frac{193}{138} = 1.4$	39	38	91	113	50

urinary sugar and qualitative fasting blood sugar tests were made pre operatively on 137 of the diabetic patients In one case there was no information regarding laboratory tests and the laboratory findings were in complete for the remaining 5 diabetics Among the diabetic amputees men and women were almost equally represented

No ideal prognostic classification of diabetes mellitus exists Patients may be grouped with respect to age at onset duration and the disease s tendency to be accompanied by vascular complications in the eyes kidneys heart and lower extremities The two former criteria were used in the present investigation But since the diabetic condition may have a subclinical course for several years and the interval between the true onset of diabetes and the day the patient comes under medical management may vary greatly between subjects neither the age at onset nor the dura tion of diabetes can reliably be determined

For most of the diabetics *i e* 85 per cent the amputation age was 60—79 years Among diabetics with amputation ages below 70 years 30 per cent were men and 20 per cent were women 12 male and 1 female diabetics were less than 60 years old at the time of the amputation (See Table 5 2)

Reckoned from the year diabetes was diagnosed by a physician and treatment instituted to the year of the first amputation proximal to the ankle joint the clinically known durations of diabetes for these patients are set out in Table 5 3 The mean duration was 8 7 years In 16 patients

Duration years	No	%
< 1	16	11
1–5	44	31
6–10	22	15
11–15	24	17
16–20	17	12
> 20	14	10
Unknown	6	4
Total	143	100

Table 5 3 Clinically known duration of diabetes among patients whose amputation was due to diabetic gangraene

Age of onset	No	%
< 30	1	1
30–39	3	2
40–49	16	11
50–59	41	29
60–69	44	31
70–79	29	20
80–89	3	2
Unknown	6	4
Total	143	100

Table 5 4 Age at clinical onset of diabetes among patients whose amputation was due to diabetic gangraene

or 11 per cent, all with durations of less than a year, gangrene lead to the diagnosis of diabetes In 55 patients or 38 per cent the duration of diabetes exceeded 10 years and in 14 patients it exceeded 20 years Such variations in duration suggest that the clinical duration of diabetes was not linearly related to the development of gangrene

The ages at the onset of diabetes were distributed as shown in Table 5 4 The age at onset was taken as the age when diabetes was diagnosed by a physician and treated The median age at onset was 62 5 years The majority, 85 patients were 50—69 years old at onset of diabetes Diabetes had set in before the age of 50 in 20 patients

The chief mode of therapy had been insulin plus diet for 95 patients or 66±8 per cent diet only for 42 patients or 29±8 per cent, and oral medi

cation plus diet for 5 patients or 4 per cent Information on treatment was not available for one patient

Among the 143 diabetic amputees in the 331 Series 36 had both legs amputated At the time of the first amputation 30 of the remaining 107 unilateral amputees exhibited signs of circulatory disturbances in the un amputated leg in the form of intermittent claudication chronic ulceration or amputated toes Signs of circulatory disturbances in the other leg were present throughout the period of observation in 66 patients A year at most after the first amputation 14 patients were subjected to amputation on the other leg

At the time of the amputation only 20 diabetics or 14 per cent of the diabetic amputees lacked diagnosed signs of vascular disease other than that which made amputation necessary However 8 of these 20 patients died within three months of the operation the cause of death in all cases being disease of the circulatory system This suggests that the incidence of intercurrent vascular diseases probably exceeds that recorded in the present investigation It seems likely that the patient or the examining physician may have overlooked such diseases a possibility which should be kept in mind in judging the figures to be mentioned hereinafter

The frequencies of manifestations from the vascular system among the diabetics in the 331 Series were as follows (i) Cardiac disorders had been noted in 51 patients or 36 per cent of all the diabetics on admission to hospital impaired general condition was recorded for 39 patients or 27 per cent (ii) Strokes with hemiplegia were seen in 14 patients or 10 per cent (iii) Senile mental insufficiency due to arteriosclerosis was encountered in 42 patients or 29 per cent such patients exhibited anything from mild confusional states to senile dementia (iv) Disabling loss of vision affected 22 patients or 15 per cent

To give an idea of the extent and degree of vascular lesions sustained by the diabetic amputees it may be mentioned that 112 of the 125 deceased diabetics died of diseases in the circulatory system or their sequels The latter group comprised the following diagnoses generalized arteriosclerosis cerebrocardiosclerosis cerebral apoplexy pulmonary em bolism cardiosclerosis cardiac decompensation myocardial infarction and heart failure Of the 12 other deceased diabetics 5 died of malignant tumours and the last 7 of miscellaneous diseases One patient died in uraemia

Obliterative Arteriosclerosis Without Diabetes

The age and sex distributions of the non diabetic gangrene amputees in the 331 Series are shown in Table 5 2 (p 35) Non diabetics with arteriosclerosis were preoperatively tested qualitatively for urinary sugar

on several occasions but were always negative The majority, 55, were men and 38 were women Gangrene amputees below 70 years of age included 20 men and 5 women, while 19 women and 16 men were in their 80 s Men were affected with non-diabetic obliterative arteriosclerosis in greater numbers and at lower ages than women

The amputation age exceeded 70 years for the large majority of patients, namely 73 per cent The largest amputation age group was 80—89 years with 38 per cent

At the time of the amputation the non diabetic gangrene amputees exhibited a wide range of vascular abnormalities additional to that constituting the amputation cause These included (i) Cardiac disorders in 30 patients or 32 per cent (ii) Subsequent contralateral amputation in 10 patients, 24 of the remaining 83 patients suffered from circulatory disturbances in the intact leg (iii) Strokes with hemiplegia in 13 patients or 14 per cent (iv) Senile mental insufficiency in 24 patients or 26 per cent On admission to hospital 19 patients or 20 per cent had ' impaired general condition Death was due to disease in the circulatory system in 65 or 92 per cent of the 71 deceased patients

Diabetic Compared with Non-Diabetic Gangrene Amputees

The 236 subjects in the 331-Series undergoing amputation for peripheral obliterative arteriosclerosis included 143 diabetics and 93 non diabetics the non diabetics to diabetics ratio being 0 65 After 1954 the number of gangrene amputees rose ($P<0\ 001$) the increase being highest ($P<0\ 001$) for non diabetic gangrene amputees (Table 5 5 and Fig 5 1) Gangrene

Table 5 5 Distributions of amputation causes among leg amputees in the 331 Series

Year	Arteriosclerosis		Accidents	Embolism	Tumours	Miscellaneous	Total
	with diabetes	without diabetes					
1947	9	4	3	0	1	3	20
1948	15	5	3	3	1	3	30
1949	8	7	4	1	1	1	22
1950	11	7	1	3	3	0	25
1951	9	5	3	1	2	1	21
1952	13	2	3	2	0	2	22
1953	8	9	6	0	1	1	25
1954	8	5	1	2	1	4	21
1955	17	7	6	4	2	2	38
1956	14	9	3	3	0	4	33
1961	31	33	2	6	2	0	74
Total	143	93	35	25	14	21	331

amputees with and without diabetes did not differ in the frequency of vascular abnormalities (see Table 5 6)

As a rule the diabetics had somewhat lower amputation ages than the non diabetic gangrene amputees The median age at amputation was 69 years for diabetics and 72 years for non diabetics The proportions of men and women were equal in the group of diabetic gangrene amputees while in the corresponding group of non diabetics the majority were men Above knee amputees were in majority among both diabetics and non diabetics non diabetic above knee amputees were somewhat more numerous than diabetic

Table 5 6 Complicating disabling diseases in patients whose amputation was due to obliterative arteriosclerosis with or without diabetes

Complication	Obliterative arteriosclerosis with diabetes		Obliterative arteriosclerosis without diabetes	
	No		No	
Cardiac distress	51	35 7	30	32.2
Multiple manifestations of vascular disease	64	44 8	35	37 6
Impaired general condition	39	27.3	19	20 4
Strokes	14	9 8	13	14 0
Senile mental insuffiency	42	29 4	24	25 8

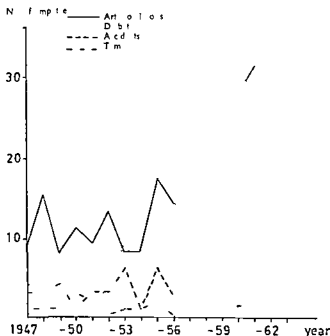


Fig 5 1 Changes in amputation causes in Gothenburg 1947—1956 and 1961

Men dominated among the traumatic amputees Indeed males were six times as numerous as females in this group The majority, 30 patients or 86 per cent, were less than 60 years old (see Table 5 2, p 35)

Yearly frequencies are presented in Table 5 5 and Fig 5 1 The number of traumatic amputees was on the whole unchanged over the period observed Owing to the small frequencies no far reaching conclu sions are justified Despite increased motor traffic and industrial mechanization the number of traumatic amputees did not rise The average frequency of traumatic leg amputees in Gothenburg is less than 1 100 000

The amputation was performed on the day of the accident in 21 cases, after 1 to 15 days in 3 cases, after 15 to 29 days in 4 cases and after more than a month in 7 cases Signs of inebriation were noted shortly after the accident in 4 patients Traffic accidents were in majority with 24 patients and among these tram and railway accidents dominated followed by motor cycle accidents Industrial accidents caused 14 amputations 6 of them taking place in traffic The group of fell over trauma comprised 2 patients, both of whom sustained a fracture of the lower leg complicated by infection These two patients were subjected to amputation several months after the accident because it had not been possible to control the infection For 5 patients the amputation age was less than 15 years, the trauma in these children and youngsters being caused by two train acci dents a motor cycle accident, a car accident, and the aforementioned vascular injury (cf p 34)

A high proportion of the traumatic amputees sustained multiple injuries

Type of fracture	No of patients
Fracture of radius	5
Fracture of skull	3
Fracture of vertebra with spinal cord injury	1
Dislocation of elbow	1
Ankle fracture	1
Fracture of humerus with radial nerve injury	1
Fracture of femoral shaft	1
Fracture of ulnar shaft	1
Total	14

Table 5 7 Fractures among the 35 patients whose ampu tation was due to accidents in the 331 Series

(Table 5 7) The accident was fatal for one seventh of the patients The most serious injuries were caused by motor cycle and train accidents

The diagnoses of embolism and thrombosis as amputation causes could not always be documented clinically It cannot be ruled out that some patients with obliterative arteriosclerosis might have been included in the embolism and thrombosis group and vice versa because emboli and thrombi not seldom complicate primary arteriosclerosis No diabetics were included in the group of patients undergoing amputation for embolism or thrombosis For 25 patients in the 331 Series the amputation cause was thrombosis or embolism The age and sex distribution of these patients

Table 5 8 Types of tumour causing amputation in the 331 Series

Malignancies	Number of Patients
Primary	
Osteogenic sarcoma	5
Fibrochondrosarcoma	2
Melanotic sarcoma	1
Chondromyxosarcoma	1
Not specified	1
Total	10
Metastasis from	
Hypernephroma	1
Cancer of the breast	1
Total	2
Combined with other causative factors	
Cancer secondary to burns	1
Cancer secondary to chronic osteomyelitis	1
Cancer of ovary (metastasis to pelvis suspected of including large vessels) alternatively peripheral obliterative arteriosclerosis	1
Total	3
Semimalignant and benign	
Osteoclastoma	1
Cavernous haemangioma	1
Total	2
Grand total	17

appears in Table 5 2 (p 35) 10 patients were 70—79 years old and constituted the largest age group There were no sex differences Embolectomy was carried out on two patients, 3 and 15 days before the amputation Above knee amputations were more common with 19 patients Of the 25 patients in this group, 15 died within six months of the operation

Two amputees had an aneurysm of the popliteal artery and attempts to reconstruct the vessel were unsuccessful

Particulars about the 17 tumour amputees in the 331 Series are given in Table 5 8 All tumours were diagnosed preoperatively and confirmed by biopsy The age and sex distribution is shown in Table 5 2 10 of these patients, the majority, were less than 50 years old Of the 5 amputees with osteogenic sarcoma, one is still alive 13 years after the amputation, the other 4 dying within 4 years postoperatively 2 pathological fractures were observed and both of them were due to metastases In one of these cases the amputation was performed in the terminal stage of the disease in order to relieve the patient of pain The small number of tumour amputees 17 during 11 years in Gothenburg, illustrates the relative rarity of this amputation cause

CHAPTER 6

Postoperative Course

Amputation Level

In most publications above knee amputations have been commoner than below-knee amputations (McKenzie 1953 Gingras *et al* 1954 Dale & Capps 1959 Jansen 1960 Bugel & Karlsson 1961 Widolf 1961 Dale & Jacobs 1962 Fellander Hallberg & Storck 1962 Lundholm 1963, Lempke *et al*, 1963) However the series studied by Alffram & Holmquist (1961) included a higher proportion of below knee amputees than of above-knee amputees

In McKenzie s study 50 of the 344 patients or 15 per cent were bilateral amputees 38 of them being bilateral above knee amputees Gingras *et al* reported that 19 or 21 per cent of his 90 patients were bilateral amputees 10 of them bilateral above knee amputees Among Jansen s 669 leg-amputees there were 108 bilateral amputees the majority of whom were bilateral above knee amputees Fellander Hallberg & Storck reported a high frequency of bilateral amputees and about one third of the surviving above knee amputees were bilateral

The surgeon s decision when the amputation level seems elective may be influenced by a desire to obtain the highest possible primary healing rate Alternatively he and the patient may be prepared to risk a lower amputa tion level in order to have the chance of achieving better ultimate function

Unilateral Amputees

Classification of the amputation level other than above or below the knee was not possible A patient exarticulated in the knee joint was assigned to the group of above-knee amputees None of the patients in the 331 Series had been exarticulated in the hip joint or hemipelvectomized

As appears from Table 6 1 the distribution of above knee and below-knee amputees varied with amputation age In the amputation age group 0—29 years above knee amputees were preponderant with 12 of 17 patients Conversely among the 48 patients with amputation ages of 30—

Table 6 1 Influence of various factors on amputation level

	Sex		Age									Cause					
	M	F	0—9	10—19	20—29	30—39	40—49	50—59	60—69	70—79	80—89	Art scler with diabet	Art scler without diabet	Accident	Tumours	Embolism	Miscellaneous
Above knee	88	73	1	4	7	5	3	11	41	56	35	56	56	15	10	17	9
Below knee	75	42	2	1	2	8	5	16	34	37	10	51	27	19	3	6	9

59 years 29 were below knee amputees At amputation ages of 60 years and up above-knee amputees were once again in the majority with 132 of 213 patients

This difference in amputation level frequencies between the amputation age groups can partly be accounted for by the amputation cause which is closely associated with the amputation age and greatly influences the choice of amputation level Tumours in most cases require amputation above the knee and most such patients were in the amputation age group below 30 years Traumatic amputations dominated at amputation ages of 30—59 years, and the commonest amputation level in such patients was below the knee Arteriosclerosis with or without diabetes and thrombo embolism are the outstanding amputation causes in elderly patients whose legs generally are amputated above the knee This is borne out by the present investigation where the group of 83 non diabetic patients whose leg was amputated owing to obliterative arteriosclerosis contained 56 above knee amputees Similarly the group of 23 thromboembolic patients included 17 above-knee amputees The distribution of amputation levels was closely similar among the diabetic patients with 56 above knee amputees and 51 below-knee amputees

The proportion of above knee amputees was higher among women than among men Of the 115 female unilateral amputees 63 per cent were above knee and 37 per cent below knee amputees The corresponding figures for men were 54 and 46 per cent

Bilateral Amputees

The 331-Series included 53 bilateral amputees 33 men and 20 women Among these bilateral amputees the 60—79 years amputation age group was most numerous with 36 patients Only one patient was younger than 49 a 12 years old girl whose second leg like the first had been amputated above the knee owing to metastasizing fibrochondrosarcoma (cf Table 6 2)

Table 6 2 Amputation causes and amputation level in bilateral amputees in 331 Series

Amputation Cause	Amputation level					
	above knee Bilateral		below knee Bilateral		above and below knee	
	men	women	men	women	men	women
Arteriosclerosis with diabetes	5	7	10	4	5	5
Arteriosclerosis without diabetes	6	0	1	0	2	2
Accidents	0	0	1	0	0	0
Tumours	0	1	0	0	0	0
Miscellaneous	2	1	1	0	0	0
Total	13	9	13	4	7	7

Among the bilateral amputees the largest group comprised 22 bilateral above knee amputees followed by a group of 17 bilateral below knee amputees and a group of 14 above and below knee amputees

In 47 patients or 96 per cent the amputation cause was peripheral vascular disease with diabetic gangrene in 36 and nondiabetic gangrene in 11 patients The time elapsed from the primary amputation to the amputation of the second leg was one year or less for 26 1—3 years for 14 and over 3 years for 13

Wound Healing

Several workers have reported healing problems after leg amputation The results of wound healing specified in the literature have been listed in Table 6 3

Few have attempted to define what is meant by primary wound healing Hence variations in healing may to some extent be due to differences between the adopted criteria for healing The table shows that after leg amputations the frequency of secondary healing ranged between 12 and 73 per cent and that of reamputations between 3 and 35 per cent Healing has consistently been inferior after below knee amputations Dale & Jacobs (1962) observed that diabetic gangrene amputees healed primarely more often than non diabetic gangrene amputees Lempke *et al* (1963) and Harris Schwarz & Weese (1961) however were unable to discern any healing differences between gangrene amputees with and without diabetes

Table 6 3 Course of wound healing after leg-amputation in the literature

Authors	Year of publication	No of patients	Amputation level	Cause of amputation	Reamputations No	Reamputations %	Secondary healed No	Secondary healed %
Conway & Meigher	1942	46	Toe to-above knee	Diabetics	16	35*	—	—
Silbert & Haimovici	1950	196	Below knee	Gangrene with and without diabetics	2	3	18	27°
Smith	1956	50	Below knee	Diabetics	—	6		
Kelly & Janes	1957	245	Below knee 131 Above knee 114	Pheripheral vascular disease	9	9	41 31	20* 18
Dale & Capps	1959	284	Below knee 65 Above knee 219	Various causes mostly peripheral vascular disease	— —	— —	33 75	51 34
Schlitt & Serlin	1960	96	Below knee Above knee	Peripheral vascular disease	— —	— —	9 10	32 15
Harris *et al*	1961	47	Above-ankle	Peripheral vascular disease	—	19	—	25
Alffram & Holmquist	1961	149	Above-ankle	Various causes mostly peripheral vascular disease	—	11	—	—
Hoar & Torres	1962	100	Below knee	Diabetics	3	3	12	12*
Dale & Jacobs	1962	385	Toe to above knee	Varios causes mostly peripheral vascular disease				24
			Above knee	Arteriosclerotic gangrene				25
			Below knee	Arteriosclerotic gangrene				39
Engsig — Karup	1963	806	Toe to above knee	Peripheral vascular disease		(without drainage) (with drainage)		56* 73

* = results deduced by this writer from the publications
° = healing only of amputees with primary sutures

In the present investigation information on healing was extracted from case notes As case notes often tend to be somewhat vague in regard to healing the data on healing given hereinafter should be regarded with great reservation

The case notes furnished far too little information with respect to the peripheral circulation and the adopted operative techniques so the association between wound healing and these factors could not be analyzed

The analysis of wound healing was confined to patients who survived at least a month after the operation Primary healing was considered to have taken place in those patients whose wound healed spontaneously during the first postoperative month All others were secondary healed

Of the 225 unilateral amputees 82 or 36±6 per cent healed primarily and 135 or 60±6 per cent healed secondarily Above knee amputations had a more favourable healing process No information was available for 8 patients Among the 135 secondary healed 37 underwent debridement and 18 reamputation from below to above knee The debridement group contained as many as 12 traumatic amputees and also a high proportion of below-knee amputees 25 patients The cause of all above knee reamputations on below knee amputees was gangrene

In 51 patients or 23 per cent of all the unilateral amputees the amputation below or above the knee had been preceded by unsuccessful foot and toe amputations Operations on the foot included 35 toe amputations 8 subtotal foot amputations and 8 local debridements on the foot All but one of these operations on the foot were caused by gangrene The exception was a traumatic amputation through the transverse tarsal joint which through wound failure was followed by below knee amputation

Complications

As direct sequels to the operation there occurred one case of irreversible shock one thyreotoxic crisis two cases of post traumatic anuria five cases of sepsis and seven cases of cerebral injury

Decubital ulceration over the sacrum and on the heel of the intact leg were noted in 18 patients Four of the 53 unilateral amputees who died during the first postoperative month had time to develop decubital ulcers All decubital ulcers involved gangrene amputees The majority of patients with decubital ulceration were 70—79 years old and only one was below 60 at amputation

Postoperative thromboembolism affected 18 of the 225 unilateral amputees The amputation cause in 14 of these patients was obliterative arteriosclerosis and in the other 4 it was thromboembolism All but two of these patients died during the first postoperative month

Duration of treatment in surgical ward months	No	Died before discharge from surgical ward	Transferred to chronics hospital	Transferred to other institution
< 1	91	36	32	7
1—3	112	11	50	4
3—6	52	2	23	1
> 6	17	—	3	1
Out patients	6	—	—	—
Total	278	49	108	13

Table 6 4 Duration of post operative treatment for unilateral amputation in the 331 Series

Duration of Treatment

In the present context the term duration of treatment included all time spent in hospital for treatment in conjunction with a leg amputation However before treatment in the surgical department is discussed, some comments are called for about those unilateral amputees who already had been deemed in need of therapy prior to the amputation In the latter category were included all patients who had been under preoperative treatment for at least six months in a hospital for chronics or a similar institution It appeared that 30 of the 278 unilateral amputees or 11 per cent had been receiving preoperative treatment — 18 in a hospital for chronics, 9 in mental hospital, 1 in a paediatric department, and 2 in an institution for sociomedical cases 26 of these 30 preoperatively treated patients underwent amputation owing to peripheral vascular disease and the remaining 4 for miscellaneous causes

Information on the duration of postoperative treatment is presented in Table 6 4 None of those surviving the first month spent less than a month in the surgical department One expression of the amputee s need of prolonged postoperative treatment is the high frequency of patients transferred to Vasa Sjukhus a hospital for chronics, which admitted 114 or 41 per cent of the 278 unilaeral amputees 20 of these were discharged from Vasa Sjukhus after 6 months to a year and 58 after more than a year Of the unilateral amputees with diabetes 57 or 53 per cent were transferred to Vasa Sjukhus The same applied to 45 or 55 per cent of the non diabetic unilateral gangrene amputees The large majority — 112 patients or 98 per cent — of the transferees to Vasa Sjukhus were over 60 years of age After treatment in the surgical department 31 or the 53 bilateral amputees

were transferred to Vasa Sjukhus where 11 of them remained for more than a year Altogether as many as 150 patients or 45 per cent of the 331 Series required continued treatment in a department for chronics

Survival Time

Data on the postoperative mortality of amputees in previous investigations have been collected in Table 6 5 showing that the postoperative mortality rate varies between the limits of 7 per cent as reported by Hoar & Torres (1962), and 50 per cent as observed by Lewin & Dealey (1955) The figures in the table are not comparable because the series of patients varied widely in size and composition and also because the concept post operative mortality has not been consistently defined

Several workers have studied the survival time after amputation (Smith 1956 Alffram & Holmquist 1961 Hoar & Torres 1962 Fellander Hallberg & Storck 1962) The mean survival time varies from 5¹/ years in Smith s series to 2 years in that of Hoar & Torres Silbert & Haimovici noted that of 16 postoperative deaths 8 were due to heart failure and 2 to pulmonary embolism Alffram & Holmquist stated that the cause of death *was identical to the amputation cause in 12 of 16 deaths among amputees* below 60 years of age Dale & Jacobs pointed out that 30 of 36 post operative deaths among amputees were due to cardiovascular complications or pulmonary embolism Arteriosclerotic manifestations in the heart or brain caused most deaths in Hoar & Torres s series of amputees The same was the case in the study of Lempke *et al*

The survival time after amputation is influenced by a variety of factors Thus McKenzie (1953) observed a higher postoperative mortality rate among male than among female amputees namely 10 5 versus 6 per cent Dale & Capps (1959) reported the inverse situation with a mortality of 21 per cent for women and 14 per cent for men The mortalities recorded by Fellander Hallberg & Storck were 22 of 30 female and 27 of 57 male amputees

Silbert & Haimovici maintained that diabetics have lower mortality after below knee than above-knee amputation like Schlitt & Serlin (1960) who found a mortality of 7 per cent for below knee and 13 per cent for above knee amputees with peripheral vascular disease Conversely Lempke *et al* found no significant difference in mortality after amputation above and below the knee But Engsig Karup (1963) demonstrated death rates of 18 8 and 30 6 per cent respectively for below knee and above knee amputees

In McKenzie s series the death rate rose with age Similary Schlitt & Serlin noted a mortality of 12 per cent in the 61—70 years amputation

Table 6.5 Postoperative mortality and survival time in published series

Authors	Year	Patient category			Postoperative mortality		Mean survival time after 0.5 years, 1 year etc.
		No	Cause	Level	No	%	
Levin & Dealy	1935	24	Diabetics	Above knee	12	50	—
Solley	1942	34	Diabetics	Toe to-above knee	—	26.5	—
Silbert & Haimovici	1950	172	Diabetics	Below knee	16	9.3	—
Smith	1956	50	Diabetics	Below knee	—	12	Mean survival time 5.5 years
Schlitt & Serlin	1960	96	Peripheral vascular disease	Toe to-above knee	13	13.6	—
Alffram & Holmquist	1961	149	Peripheral vascular disease	Below and above knee	20	13.4	47 (31.5%) dead within 6 months postoperatively. 40% aged over 60 dead within 1 year postoperatively. Mean survival time 2 years 3 months
Hoar & Torres	1962	100	Diabetics	Below knee	7	7	Mean survival time of 30 discharged patients 2 years
Dale & Jacobs	1962	385	Miscellaneous causes mostly peripheral vascular disease	Below and above knee	36	11	—
Fellander *et al*	1962	87	Miscellaneous causes mostly peripheral vascular disease	Below and above knee	—	—	40.5% dead within 3 years, 71.7% within 6 years post operatively
Lundholm	1963	93	Miscellaneous causes mostly peripheral vascular disease	Below and above knee	22	24	—
Lempke *et al*	1963	200	Peripheral vascular disease	Toe to-above knee	24	12	—

* = including three patients with arm amputations

age group and of 44 per cent for ages from 71 years Fellander Hallberg & Storck found that the amputation age influenced the mortality especially at ages over 60 years

In the study of Lempke *et al* non diabetic gangrene with intercurrent cardiac disease resulted in a conspicuously high mortality moreover the same investigation disclosed that the mortality associated with arteriosclerotic heart disease was unaffected by amputation level and intercurrent diseases

* * *

For the purpose of mortality calculations in the present investigation the survival time of bilateral amputees was calculated from the date of the last amputation

In the 331-Series the postoperative mortality was 59 patients or 18 per cent during the first month 119 or 36 per cent during the first 6 months and 136 or 41 per cent during the first year (cf Table 6 6)

The mean survival time for the entire 331 Series was one year and eight months the corresponding figures for patients with amputation ages under and over 60 years being 2 years and 2 months and 1 year and 7 months respectively The mean postoperative survival time exhibited no sex differences

Of the group with amputation ages below 60 years three male traumatic amputees with severe cerebral lesions and one female amputee with thyreotoxic crisis and extensive frostbite died within the first postoperative

Table 6 6 Dead within 1 t postoperative year in the 331 Series

Survival time	Amputation age < 60 years		Amputation age > 60 years	
	Men	Women	Men	Women
< 1 week	3	1	16	10
1 week–1 month	3	1	12	13
1–3 months	4	1	17	19
3–6 months	0	0	9	10
6–12 months	2	0	6	9
Total	12	3	60	61

week In the same group 12 men and 3 women — the majority diabetic-gangrene or traumatic amputees — died during the first postoperative year

Patients over 60 years old at the time of amputation who died during the first postoperative year comprised 57 diabetic and 47 non diabetic gangrene amputees, 15 thromboembolic 1 traumatic and 1 osteomyelitic amputees, among whom 60 were men and 61 women

Of the 53 bilateral amputees 22 died within a year of the last amputation

The causes of death were in 185 cases, or 75 per cent of the 256 cases based on findings at a *post mortem* examination and in the remaining cases on the diagnoses specified on the death certificates filed at Public Register Offices

The causes of death during the first postoperative year were distributed as shown in Table 6 7

Table 6 7 Causes of death *for patients dying during 1st* postoperative year in the 331 Series

Cause of death	Patients < 60 years		Patients > 60 years	
	No	%	No	%
Cardiovascular disease	5	33	109	90
Tumours	2	13	7	6
Miscellaneous	8	53	5	4
Total	*15*	*99*	*121*	*100*

Among patients over 60 years of age dying during the first year arteriosclerosis with fatal cardiopulmonary and cerebral complications caused 90 per cent of the deaths The amputation was not *per se* the direct cause of any death in the 331-Series

The causes of death and the amputation causes coincided in 28 or 90 per cent of the 31 patients who were younger than 60 years at the amputation and died during the subsequent 5 years Merely 3 of these patients died of a disease other than that which had made the amputation necessary Similarly in the group with amputation ages over 60 years the causes of amputation and death could be traced to the same basic disease in 89 per cent of the cases The most common condition was arteriosclerosis which gave rise to gangrene and in more advanced stages to fatal complications from the heart

Analysis of survival times were facilitated by dividing the 331 Series both into patients younger and older than 60 years at the time of amputation and also into new amputees added during the periods 1947—1951 1952—1956 and 1961 the survival time being defined as the interval between the last amputation and the day of death (See Tables 6 8 6 9) For the group of patients with amputation ages over 60 years the survival times were compared with the annual mortality at different ages as given in Statistical Yearbook for Gothenburg

Alive after 5 years were 42 of 67 or 63 per cent of those patients who were younger than 60 years at amputation during the period 1947—1956 (Table 6 8) During the periods 1947—1951 1952—1956 and 1961 the survival rates one year postoperatively were 82 93 and 40 per cent respec tively Three years after the last operation about 25 per cent of the group younger than 60 years at amputation had died

Table 6 8 Survival rate of amputees with amputation performed befor the age of 60 in the 331 Series

Period	No of amputees	No of survivors after										Alive 28 2 1963	
		1 year		2 year		3 year		4 year		5 year			
		No		No		No		No		No		No	
1947—1951	38	31	81	28	73.6	28	73.6	24	63.1	22	57.8	17	44.7
1952—1956	29	27	93.1	26	89.6	22	75.8	21	72.4	20	68.9	18	62.0
1961	10	4	40.0									4	40.0

Table 6 9 Survival rate of amputees with amputation performed after the age of 60 as compared with normal life expectency in the 331 Series

Period	No	331 Series Normal life expectancy	Survival rate after										Alive 28 2 1963
			1 year		2 year		3 year		4 year		5 year		
			No		No		No		No		No	%	
1947—1951	80	331 Series	43	53.8	33	41.3	25	31.3	20	25.0	13	16.3	2
		Normal life expectancy	75	93.8	70	87	65	81.3	62	77.	58	72	—
1952—1956	110	331 Series	61	55.5	46	41.8	29	26.5	25	22	22	20.0	17
		Normal life expectancy	103	93.6	97	88	91	82.7	86	78.2	81	73.6	—
1961	64	331 Series	29	45.3	—	—	—	—	—	—	—	—	27
		Normal life expectancy	59	92.2	55	85.9	51	79.7	47	73.4	44	68.8	—

Data on survival times for patients older than 60 years at the time of amputation are presented in Table 6 9 and have been plotted in Fig 6 1 At the end of the first postoperative year the survival rates during the periods 1947—1951 1952—1956 and 1961 were 54, 56 and 45 per cent respectively, implying that about half the patients in this older group died within a year of the last amputation Four years postoperatively 25 per cent of those patients subjected to amputation in 1947—1951 and 23 per cent of those undergoing amputation in 1952—1956 were alive This means that approximately three quarters of the patients died within four years postoperatively Analogously, after five years 13 of 80 or 16 per cent of the new amputees in 1947—1951 and 22 of 110 or 20 per cent of the new amputees in 1952—1956 remained alive The mortality of these elderly amputees was highest during the first postoperative year, whereupon it fell and reached a minimum between the 4th and 5th postoperative years

During the periods 1947—1951 and 1952—1956 those undergoing amputation older than 60 years and surviving at least two years post

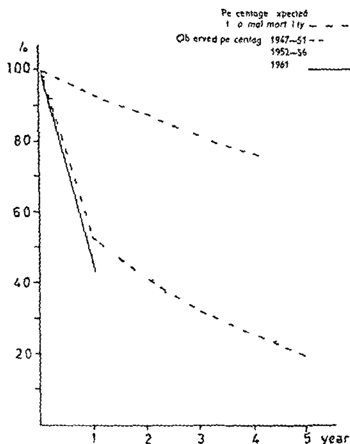


Fig 6 1 Percentage of amputees over 60 years old surviving in Gothenburg after 1 2 3 4 and 5 years 1947—1951 1952—1956 and 1961

operatively were about half as many as one would expect from the figures for the gross population A similar low survival rate was recorded as little as a year after amputation in 1961 The observed survival time for the older amputees five years after the operation was on average less than a quarter of that specified in Statistical Yearbook for Gothenburg as applying to a population having a similar age distribution The great survival time difference between the amputees and a corresponding segment of the gross population is illustrated in Fig 6 1

The periods exhibit no differences in the number surviving the first postoperative year The observation period was too short for calculation of survival rates for the second postoperative year among those under going amputation in 1961

Patients older than 60 years at amputation with peripheral obliterative arteriosclerosis were selected for analysis of some factors that seemed likely to be capable of affecting the survival time namely sex amputation level amputation age and intercurrent disease with a usually fatal course No allowance was made for any individual variations present between the various vascular disorders The life span of the normal population is known to have increased during recent decades Such deviations could not be taken into account in this analysis Nor could such factors be taken into consideration as the operative technique and the social background both of which conceivably might influence the mortality

In order to make the analysis easier to understand the material was rearranged so as to have eight categories one characterized by the presence and another by the absence of each of the four factors thus under sex *male female under amputation* level above knee below knee under amputation age 60—74 years 75—89 years under intercurrent disease presence and absence Here the term usually fatal disease connotes severe impairment of general condition before during or after the first post operative month e g failing heart function pulmonary embolism renal insufficiency metastasizing cancer and lastly cerebral haemorrhage

The factors cannot be analyzed individually i e the whole series cannot simply be classified with respect to the alternatives under a single factor and *the survival time studied in the groups thus obtained For interaction* may exist between two or more factors Occasionally the effect of a single factor may obscure the other factors It is not certain that age has the same action in both sexes nor that the effect of amputation level is independent of intercurrent fatal disease Hence the entire series must be subdivided with respect to all the factors (Table 6 10) These four factors yield 16 groups in which the annual mortality rate in per cent must be sought

Table 6 10 Relations between sex amputation level amputation age intercurrent fatal disease and 1 year mortality for amputees over 60 years with peripheral vascular disease

Sex	Men 125								Women 114							
Amputation level	Above knee 78				Below knee 47				Above knee 77				Below knee 37			
Amputation age No	75—89 33		60—74 45		75—89 15		60—74 32		75—89 32		60—74 42		75—89 16		60—74 21	
Intercurrent fatal disease	with 12	without 21	with 23	without 22	with 7	without 8	with 17	without 15	with 19	without 16	with 25	without 17	with 9	without 7	with 14	without 7
1 year mortality	7/12	8/21	13/23	1/2	5/7	3/8	10/17	1/5	15/19	1/2	12/25	8/17	7/9	3/7	2/7	1/7

Table 6 11 Analysis of variance in 1 year mortality due to sex amputation level, amputation age and intercurrent fatal disease

Cause of variation	Degrees of freedom	Variance	P
Sex	1	0 0001	—
Level	1	0 1984	0 01 < P < 0 02
Age	1	0 60.8	0 001 < P < 0 005
Fatal disease	1	1 0106	P < 0 001
Interaction between sex and leve	1	0 0694	—
sex and age	1	0 2730	0 01 < P < 0 025
sex and fatal disease	1	0 0040	—
level and age	1	0 490	0 01 < P < 0 05
level and fatal disease	1	0 15 4	0 01 < P < 0 05
age and fatal disease	1	0 0777	—
Errors	5	0 020	—

To estimate the effect of the four factors, if one or more interactions were present the annual mortality proportions were subjected to analysis of variance with the aid of Yates s technique

Analysis of variance yielded the results presented in Table 6 11 The residual variance was estimated from the sum of squared interactions of order 2 or higher The factors considered interact in a complex manner

Interactions significant on the 5 per cent level or better were present between sex and amputation age amputation level and amputation age and also between level and intercurrent fatal disease On the other hand independent effects were exerted by sex and amputation level, intercurrent fatal disease and amputation level as well as amputation age and inter current fatal disease

Allowance must be made for these interactions in evalutions of the significance of the various factors This implies that when we study say amputation level we must divide the patients into four subgroups corres ponding to each of the two categories under each factor amputation level interacted both with amputation age and with intercurrent fatal disease The one year mortality in each such subgroup was studied by γ analysis

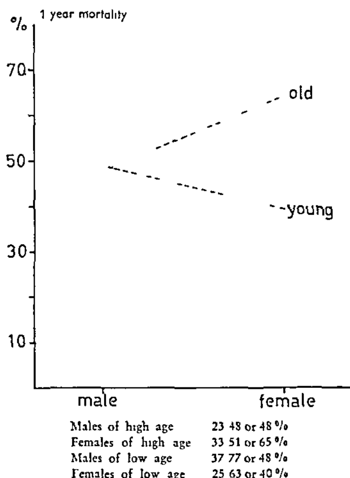
Table 6 12 γ^2 tests of strength of interactions between sex amputation age amputation level and intercurrent fatal disease

= significant on 5 per cent *level*

			γ^2
Sex	5–89 years		2 19
	60– 4 years		0 6 4
Amputation level	75–89 years	With fatal disease	0 076
		Without fatal disease	0 009
	60–74 years	With fatal	0 137
		Without fatal	4 19 *
Amputation age	Men	Below knee	0 25
		Above knee	0 210
	Women	Below knee	4 737 *
		Above knee	1 854
Intercurrent fatal disease	Below knee		5 661 *
	Above knee		2.295

Differences marked with an asterisk ( ) in Table 6 12 are significant on the 5 per cent level or better In order to simplify interpretation of the results, the observations made have been illustrated graphically in Fig 6 2, where the annual mortality in per cent is marked off along the ordinate and the two categories under each factor appear along the abscissa Mortality differences between groups are represented by the slope of the lines the steeper the slope the greater the probability of a significant mortality difference between the groups under study Significant differences are denoted by solid lines others by broken lines

The only interaction between sex and amputation age was studied by dividing the patients into older 75—89 years and younger 60—74 years patients It appears that the 1-year mortality for older men was 48 per cent (23/48) versus 65 per cent (33/51) for older women These mortality rates are not significantly unequal (broken line in Fig 6 2) The corres-

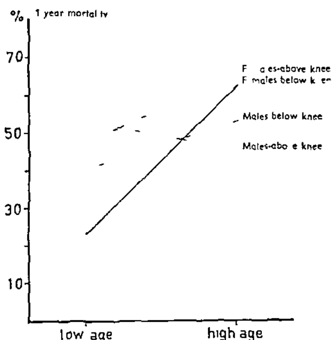


Males of high age	23 48 or 48 %
Females of high age	33 51 or 65 %
Males of low age	37 77 or 48 %
Females of low age	25 63 or 40 %

Fig 6 2 Effect on survival time of sex combined with age at amputation

ponding figures for younger men and women were 48 per cent (37/47) and 40 per cent (25/63) the difference not being significant We see therefore that sex lacked significant effect on one year mortality in this group of gangrene amputees

One-year mortality is influenced by amputation age interacting both with sex and with amputation level (Fig 6 3) Hence the patients must be divided into four groups male above knee amputees male below knee amputees female above knee amputees and female below knee amputees Evidently amputation age influenced the mortality of female below knee amputees the higher the amputation age the greater the one year mortality No significant differences appeared in the other groups The

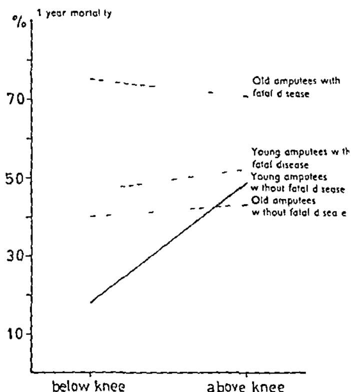


Males below knee and hı h age	8 15 or 53 %
Males below knee and low age	13 32 or 41 %
Males above knee and high age	15 33 or 46 %
Males above knee and low age	24 45 or 53 %
Females below knee and high age	10 16 or 63 %
Females below knee and low age	5 21 or 24 %
Females above knee and high age	23 35 or 66 %
Females above knee and low age	20 42 or 48 %

Fig 6 3 Effect on survival time of a e at amputation combined with sex and amputation level

one year mortality rate for female below-knee amputees with high amputation age was 63 per cent (10/16) while it was 24 per cent (5/21) for the corresponding group with low amputation age.

Amputation level influences the one-year mortality rate by interacting with amputation age and with intercurrent fatal disease (fig. 6.4). It will be seen that a significant and conspicuous mortality rate difference was present between below knee and above knee amputees with low amputation age. Thus the 1-year mortality rate in this group was 18 per cent (4/22) for below knee amputees and 49 per cent (19/39) for above-knee amputees. No other differences were significant.



Old amputees with fatal disease and above knee	22/31 or 71 %
Old amputees with fatal disease and below knee	12/16 or 75 %
Old amputees without fatal disease and above knee	16/37 or 43 %
Old amputees without fatal disease and below knee	6/15 or 40 %
Young amputees with fatal disease and above knee	25/48 or 52 %
Young amputees with fatal disease and below knee	14/31 or 45 %
Young amputees without fatal disease and above knee	19/39 or 49 %
Young amputees without fatal disease and below knee	4/22 or 18 %

Fig. 6.4. Effect on survival time of amputation level combined with age at amputation and intercurrent fatal disease.

Lastly the effect was studied of intercurrent fatal disease at the time of the amputation on the 1 year mortality rate (Fig 6 5) It appears that the 1 year mortality of below knee amputees was significantly higher for those with than for those without intercurrent fatal disease This mortality rate also tended to be higher in above-knee amputees with intercurrent disease

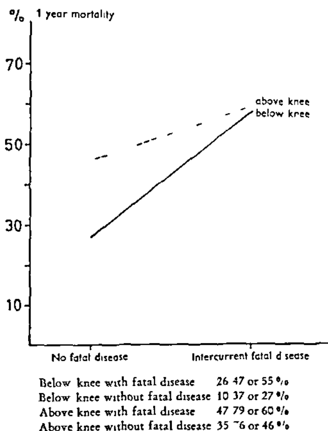


Fig 6 5 Effect on survival time of intercurrent fatal disease combined with amputation level

CHAPTER 7

The Leg-Amputee Population Trend up to 1970

As an aid in planning hospital and rehabilitational facilities for leg-amputees an attempt was made to predict the frequencies of living leg-amputees over 60 years of age for each of the years 1962—1970

While the number of new leg-amputees below 60 years of age remained substantially constant during the observation period 1947—1962, the frequency of such subjects over 60 years rose If this trend should continue, there are good grounds for creating greater resources to care for the future needs of these patients

This analysis was based on figures for Gothenburg s population trend from a prognostication by Gothenburg s Statistical Office in 1963 (Table 7 1) The expected numbers of elderly amputees were found by multiplying the observed mean amputation rates for males and females over

Table 7 1 Population of Gothenburg over 60 years of age at end of years 1960—1970

	Age 60—69			70—79			80—89			90—			> 60		
Year	Men	Women	Tot	Men	Women	Tot	Men	Women	Tot	Men	Women	Tot	Men	Women	Tot
1960	17150	20540	37600	8725	11650	20375	1925	3400	5325	75	275	350	27875	35775	63650
1961	17525	21100	38625	9150	12075	21225	2025	3525	5550	100	275	375	28800	36975	65775
1962	17975	21625	39600	9475	12650	22125	2150	3750	5900	100	300	400	29700	38325	68025
1963	18350	22175	40525	9850	13075	22925	2275	3875	6150	100	300	400	30575	39425	70000
1964	18825	22675	41500	10150	13475	23625	2450	4075	6525	125	325	450	31550	40550	72100
1965	19175	22975	42150	10550	14025	24575	2600	4325	6925	150	350	500	32475	41675	74150
1966	19700	23525	43225	10925	14500	25425	2775	4575	7350	150	375	525	33550	42975	76525
1967	20325	24200	44525	11225	14825	26050	3000	4850	7850	175	400	575	34725	44275	79000
1968	20875	24800	45675	11625	15325	26950	3150	5150	8300	175	400	575	35825	45675	81500
1969	21575	25600	47175	11925	15750	27675	3300	5350	8650	200	450	650	37000	47150	84150
1970	22300	26100	48400	12250	16275	28525	3475	5600	9075	200	450	675	38225	48425	86550

Table 7 2. Predicted number of living leg amputees of over 60 years old in Gothenburg 1962—1970

Year to end	Predicted Population			Predicted number of living amputees		
	Men	Women	Total	Men	Women	Total
1962	29700	38325	68025	52	39	91
1963	30575	39425	70000	61	44	105
1964	31550	40550	2100	65	50	115
1965	32475	41675	41 0	71	53	124
1966	33550	42975	76525	3	58	131
1967	34725	442 5	79000	80	59	139
1968	35825	45675	81500	82	63	145
1969	3 000	47150	84150	86	67	153
1970	38225	48425	86650	85	70	158

60 in 1960—1962 namely 0 001140 for men and 0 000605 for women by the predicted population over 60 in each of the years up to 1970 Survival times for the amputees were estimated with the aid of observations for the group of new amputees during the period 1947—1951 the only group that would provide mortality figures for a sufficient number of years The specified number of living amputees over 60 years at the end of 1962 is the sum of the numbers surviving after amputation in each of the years 1958, 1959 1960 1961 and 1962 This method does not provide an exact figure for the number of living amputees at the end of 1962 but the important figures are those for the years near 1970 rather than those for the early 1960 s Moreover the figures for the years around 1970 are influenced little if at all by any survivors after amputation before 1958 because only 2 5 per cent of patients older than 60 at the time of amputation survive for as long as 12 years Hence no allowance was made for such patients This presupposes however that the survival times for leg amputees will not undergo any significant changes before 1970 Nor was the apparent rise of the amputation rate taken into account The figures given here are of course predictions for the future and should therefore not be used as a basis for far reaching conclusions Future medical advances may perhaps reduce the number of gangrene amputees Moreover the indications for amputation may not remain constant

The estimated frequencies of leg amputees are presented in Table 7 2 and illustrated in Fig 7 1 It will be seen that the leg amputee frequency rises steadily up to 1970 most sharply for women Thus the number of

Table 8 1 Frequency of prosthesis users in published series

Authors	Year	Patient category			Prosthesis users	
		No	Cause	Level	No	%
Conway & Meigher	1942	31	Diabetics	Above knee	9	
Mc Kenzie	1953	344	> 65 years miscellaneous causes mostly peripheral vascular disease	Above ankle	171	49 7
Mc Goey	1954	105	> 65 years arteriosclerosis	Above ankle	1 patient > 70 years old used and walked with prosthesis *	
Gingras *et al*	1954	56	Majority > 50 years old with peripheral vascular disease	Above ankle	32	44*
Warren	1957	41	Arteriosclerosis	Above ankle	23	57
Claugus *et al*	1958	47	Peripheral vascular disease	Below knee	23	49
		71	50 - 70 years old	Above knee	21	30
Park & Miller	1958	18	> 55 years peripheral vascular disease	Above ankle	8	
Chapman *et al*	1959	47	Majority peripheral vascular disease	Above ankle	26	55 3*
Bertelsen & Ronn	1960	238	Over age 65 miscellaneous cause mostly peripheral vascular disease	Above ankle	120	48 5*
Schlitt & Serlin	1960	96	Peripheral vascular disease	Toe to-above knee	12	12 5
Bugel & Carlson	1961	128	Mean age 65 years majority with peripheral vascular disease	Above ankle	60	47 *
Alffram & Holmquist	1961	35	< 60 years	Above ankle	29	83
		114	> 60 years miscellaneous causes		57	50
Widolf	1961	72	Tumours diabetics accident	Above ankle	60	83 3
Wolters	1961	75	> 60 years old peripheral vascular disease	Above knee	32	50*
Fellander *et al*	1962	87	Mostly peripheral vascular disease amp in 1954 and 1957	Below and above knee	16*	
Hoar & Torres	1962	100	Diabetics	Below knee	63	

* At time of follow up

Table 8.2 Frequency of prosthesis users of different patient categories in the 331 Series

Patient category	No	Prothesis users No	
Whole series	331	103	31
Unilateral amputees	278	94	34
Bilateral amputees	53	9	1
Unilateral amputees 60 year old	213	45	21
Unilateral amputees < 60 year old	6	50	–
Unilateral amputees 60 year surviving at least 1 year	108	45	42
Unilateral amputees < 60 years surviving at least 1 year	5	49	94

A high proportion of bilateral amputees become bound to their wheel chair None of the 76 bilateral above knee gangrene amputees in Erlicher s (1958) series became prosthesis walkers The latter worker found however that practically all bilateral amputees with one functioning knee joint could learn to walk except gangrene amputees

Prosthesis Equipment and Prosthesis Walking in the 331 Series

Among the 331 patients undergoing amputation in the years 1947—1956 and 1961, analysis of prosthesis function was mainly confined to those surviving at least a year after the last amputation who were classified into three groups unilateral amputees with amputation ages under 60 years unilateral amputees with amputation ages over 60 years and bilateral amputees No grading of the patients gait was attempted

Within the first year after the last amputation 105 of the 213 unilateral amputees older than 60 years had died Of the remaining 108 unilateral amputees who survived the last amputation for a year or more 45 or 42 per cent became able to walk with their prosthesis (cf Table 8 2)

This group of 45 prosthesis walkers comprised 30 men and 15 women Below knee amputees were in the majority with 25 patients against 20 above-knee amputees Additional handicaps were present in 14 of the 45 prosthesis walkers over 60 years old at amputation which in 37 cases was due to gangrene

The group of 63 unilateral amputees surviving at least a year post-operatively who did not become prosthesis walkers comprised 30 men and 33 women Here there was thus a small preponderance of women unlike the group of prosthesis walkers with twice as many men as women Among the non walkers 39 were above knee amputees and 24 below knee amputees Accordingly the ratio of below knee to above knee amputees

Years after amputation	No of survivors	Prosthesis users	
		No	
1	85	37	43
2	69	30	43
3	46	27	58
4	39	25	64
5	33	23	69

Table 8 3 Prosthesis users among survivors over 60 years old 1 2 etc years after amputation in 1947—1956

walking with a prosthesis was nearly 1 5 times the corresponding ratio for those unable to walk with a prosthesis As many as 49 of the 63 non walker had additional handicaps The cause of amputation was gangrene in 60 or 95 per cent of the non-walkers

Of the 63 unilateral amputees who did not become prosthesis walkers 40 had and 23 had not been equipped with a prosthesis These 23 patients had not been fitted with a prosthesis because of cardiac decompensation in 11 cases senile dementia in 8 cases advanced contractures in 2 cases and, lastly marked circulatory disturbances in the intact leg in 2 cases

Only 2 of the 105 unilateral amputees who died within a year post operatively had been fitted with a prosthesis and neither became able to use it

Frequencies of prosthesis walkers in successive years among the survivors after amputation over age 60 in 1947—1956 are set out in Table 8 3 Because the observation period was too short 1961 was omitted It will be seen that the frequency of those able to use a prosthesis among the survivors rose each year after the operation Thus a year after amputation 37 of 85 or 44 per cent walked with a prosthesis three years after amputation 27 of 46 or 59 per cent did so and five years after amputation 23 of 33 surviving unilateral amputees could walk with their prosthesis, in other words 69 per cent None of those who had not become able to use a prosthesis within a year after amputation became able to walk with a prosthesis This means that the prognosis for prosthesis function is poor in patients with amputation ages over 60 years who have not learnt to walk with a prosthesis during the first postoperative year

Among the 65 unilateral amputees younger than 60 years 13 died less than a year postoperatively Two of the latter had been fitted with a prosthesis one of them managed to walk with it the other failed owing to heart disease The group of 52 surviving younger patients included 49 or 94 per cent who became prosthesis walkers, 39 men and 10 women The leg had been amputated above the knee in 22 and below it in 30 patients Additional handicaps occurred in 12 patients

As mentioned, the group of 52 unilateral amputees younger than 60 years included 3 who did not acquire the ability to walk with a prosthesis One of the latter was a mentally retarded 33 years old male epileptic whose leg was amputated below the knee for diabetic gangrene another was a woman of 55 with organic heart disease and recurrent attacks of pulmonary oedema undergoing above knee amputation for embolism and the third was a 54 years old blind man with heart disease whose leg was amputated below the knee for diabetic gangrene

Particulars about the prosthesis walkers among those bilateral amputees surviving at least a year after the last amputation are given in Table 8 4

Table 8 4 Frequency of prosthesis users and bilaterally prothesis equipped among 31 bilatelateral amputees surviving at least 1 year

Bilateral amputee	No	
Prothesis-equipped walker	9	29
non walker		22
Not prothesis equipped	15	48
Total	31	100

Of the altogether 53 bilateral amputees in the 331 Series 31 survived for at least a year after the last amputation and 9 of the latter became able to walk with prostheses namely 5 bilateral below knee amputees 3 bilateral above knee amputees and 1 above and below knee amputee At the last amputation 5 were under and 4 over 60 years old The amputation cause was gangrene in 7 tumour in 1 and an accident in 1 case No bilateral above knee amputee older than 60 years became able to walk with prostheses

Younger than 60 years at the last amputation was only 1 of the 22 bilateral amputees who never managed to walk with his prostheses Half of these 22 patients were bilateral above knee amputees As the interval between amputations varied among walkers as well as among non walkers this factor would seem to have had little or no effect on the frequency of prosthesis walkers among bilateral amputees

As has appeared elsewhere (cf Fig 2 1) all patients who were followed up were asked about phantom pains None of the interviewed patients in either the 331 Series or the 133 Series complained of reduced function due to such symptoms

In order to establish how certain factors affect prosthesis function the associations between prosthesis walking and sex amputation level and

additional handicaps were analyzed in a group of 99 patients, all of whom had undergone unilateral amputation above or below the knee for peripheral obliterative arteriosclerosis with or without diabetes and survived for at least a year after the last amputation Here additional handicaps include all conditions other than amputation that could interfere with the patient s ability to walk with a prosthesis These conditions are specified in Table 8 5

Table 8 5 Distribution of disabling diseases among 64 of 99 unilateral gangrene amputees over 60 years of age

Intercurrent disabling disease	No
Circulatory disturbances in intact leg	30
Arteriosclerotic heart disease	13
Senile mentale insufficiency schizophrenia	11
Strokes	6
Joint disorders	3
Blindness	1

The prosthesis service offered these 99 patients must be regarded as of fairly uniform standard All patients fitted with a prosthesis received their prosthesis from the *Workshop of the Orthopædic Department Gothenburg, where no major changes in organization or production took* place during the relevant period namely 1947—1956 and 1961 No pylons were issued All below knee amputees were fitted with a conventional lower-leg prosthesis provided with knee-joint mechanisms af various types and a thigh corset Above knee amputees were equipped with prostheses having a triangular socket and suspension braces for attachment to the body The knee joint of above knee prostheses consisted of a lockable central joint and above knee amputees older than 60 years were trained to walk with the knee locked One patient was admitted to the Orthopædic Department for four days for prosthesis fitting and gait training The other patients were trained in surgical wards or wards for chronics Two amputees were given gait training as out patients in the Orthopædic Department

Inadequate information on stump condition obviated analysis of the effect of this factor upon prosthesis function

At the time of amputation 42 of these 99 patients were in their 60 s 43 in their 70 s and 14 in their 80 s

The 99 patients were distributed according to sex amputation level and presence or absence of additional handicaps (See Table 8 6) Since each

Table 8.6 Relations between ability to use prosthesis and sex, amputation level and intercurrent disabling disease in 99 unilateral gangrene with amputation age over 60 years and surviving at least 1 year after his amputation

Sex	Men 55								Women 44							
Amputation level	Above knee 30				Below knee 25				Above knee [illegible]				Below knee [illegible]			
Intercurrent disabling disease	Yes 21		No 9		Yes 1[illegible]		No 1[illegible]		Yes 1[illegible]		No [illegible]		Yes 1[illegible]		No [illegible]	
Prosthesis users	Not users	Users	Not users	Users	Not users	Users	Not users	Users	Not users	Users	Not users	Users	Not users	Users	Not users	Users
	19	2	2	7	5	[illegible]	3	1[illegible]	13	3	4	3	13	2	[illegible]	4

factor was divided into two categories a 2 x 2 x 2 table was required and in each of the 8 subgroups the proportion of prosthesis walkers was analyzed in the same way as in Table 6 10 p [illegible]6 with respect to survival time Then after logit transformation analysis of variance according to Yates was carried out This disclosed that first order interactions were not significant compared with the second order interaction which was used for estimating the residual variation When all interaction effects were pooled and the variance of the residual variation was estimated with 4 degrees of freedom the following conclusions could be drawn (Table 8 7)

The frequency of prosthesis walkers among the 99 patients subject to amputation for peripheral obliterative arteriosclerosis was affected most markedly by additional handicaps Thus the frequency of prosthesis walkers

Table 8 7 Analysis of variance of sex amputation level and intercurrent disabling disease in ability to use prosthesis among unilateral gangrene amputees older than 60 years surviving at least 1 year

Source of variation		Degrees of freedom		Variance		P
Sex	(A)	1		0.3[illegible]0		—
Amputation level	(B)	1		0.3[illegible]9		—
Disabling disease	(C)	1		2.0646		0.0[illegible] < P < 0.[illegible]
Interaction	AB	1	4	0.1203	0.1[illegible]	—
”	AC	1		0.01[illegible]1		
	BC	1		0.049[illegible]		
	ABC	1		0.5066		

was significantly reduced by the presence of additional handicaps compared with the corresponding group without additional handicaps There was no significant difference between the sexes nor between below knee and above knee amputees in the frequency of prosthesis walkers No interactions existed between the factors and therefore the presence of additional handicaps affected prosthesis function independently of either sex or amputation level

The effect of additional handicaps is illustrated graphically in Fig 8 1, where the percentage of prosthesis walkers is marked off along the ordinate and the presence and absence of additional handicaps is marked on the abscissa The diagram shows that whereas 22 per cent of the patients with additional handicaps became able to walk with a prosthesis, 69 per cent of those without additional handicaps acquired this ability

While 12 or 27 per cent of the 44 women became prosthesis walkers 26 or 47 per cent of the 55 men did so

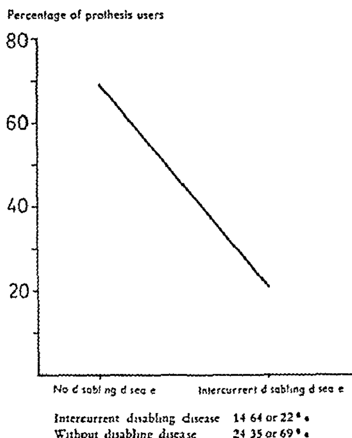


Fig 8 1 Effect on prosthesis usage of intercurrent disabling disease

In the group of 53 above knee amputees 15 or 28 per cent managed walking with a prosthesis the corresponding figures for the below knee amputees being 23 of 46 or 50 per cent

Even if the latter two differences are not significant they do suggest that proportionately fewer women than men became prosthesis walkers and also that below knee amputees tended to become prosthesis walkers more often than above knee amputees

Prosthesis Walking Prosthesis Complaints and Gait in the 133 Series

All the amputees in the 133 Series had been fitted with a prosthesis One patient did not use her prosthesis but walked with the aid of the intact leg and two crutches This was a woman of 61 who at the age of 55 had been subjected to disarticulation in the hip joint for sarcoma Though a prosthesis had been issued to her postoperatively she had received no training In addition to the amputation the patient suffered from obesity and a crural ulcer on the intact leg She was able to do light household work

The types of prosthesis the patients were fitted with are specified in Table 8 8

Table 8 8 Types of prosthesis fitted in the 133-Series

Prosthesis type	No
Canadian type exarticulation prosthesis for hip-joint exarticulation	3
Above knee prosthesis — triangular socket with suspension braces	11
Above knee prosthesis — suction socket	33
Exarticulation end bearing prosthesis for knee joint	3
Below knee prosthesis conventional type with thigh corset	90

When directly questioned whether the prosthesis caused them any trouble 91 gave negative replies and 41 complained of the prosthesis chafing when they had walked for a couple of hours At the follow up examination abrasions due to a poorly fitted prosthesis were encountered in 5 patients

The gait of these patients was classified as a mild moderate or marked limp and it was noted whether or not the patient used a cane This was a subjective assessment made at the follow up examination while the patient demonstrated his walking Details of the gait of the 132 prosthesis walkers will be found in Table 8 9

	GAIT					
	Slight limp		Moderate limp		Severe limp	
	No	%	No	%	No	%
Without cane	56	42.4	38	28.8	4	3.0
With cane	0	0.0	23	17.4	11	8.3

Table 8 9 Gait of 132 prosthesis users in the 133-Series

None of the 56 patients or 42 per cent whose gait had a mild limp used a cane This group comprised 51 below knee and 5 above knee amputees A cane was used by 33 of the 61 patients — 46 per cent of the total — whose gait had a moderate limp the latter category including 33 above-knee and 28 below-knee amputees *In the group of 15 markedly limping* patients 11 used a cane and 11 were above knee and 4 below knee amputees

CHAPTER 9

Sociomedical Function

INTRODUCTION

Gingras Mongeau & Bergeron (1954) treated 90 patient over 50 years old at the time of amputation Among the patients 82 per cent were living in their homes and the remaining 18 per cent in hospital Chapman *et al* (1959) following up 32 patients over 55 years old at amputation found that 19 were able to manage on their own 9 had to have assistance in the activity of daily living and 4 required institutional care Wolters (1961) interviewed 32 above-knee amputees older than 50 years at amputation finding that 33 per cent were institutional cases 42 per cent exhibited considerable functional impairment and 25 per cent were gainfully employed Hirsch (1961) studied 58 traumatic amputees most of them men and noted that 35 per cent of them were unable to work Russek (1961) pointed out that the leg amputee in good social circumstances as a rule had an excellent social prognosis Most of his private patients spent the rest of the lives outside hospital Alffram & Holmquist (1961) remarked that a group of 19 followed up survivors after amputation before age 60 comprised 8 working at the same job as before the amputation 5 with other jobs after the amputation 3 housewives capable of doing light household chores 2 institutional cases and 1 patient who could not be traced The same workers reported that no patient with amputation age over 60 years was gainfully employed and also that 88 of the 97 surviving patients were prosthesis walkers and 9 were confined to bed or wheelchair Fellander, Hallberg & Storck (1962) had no patients subjected to amputation after age 60 at work while 11 of the 19 with amputation ages below 60 years were gainfully employed

Classification

Six degrees of sociomedical function were used namely full restoration partial restoration self care plus self care minus domestic care and institutional care The criteria for classification were as follows

Group I Full restoration — the patient has a fulltime job with no more than normal absenteeism He feels the amputation is no serious hindrance either at work or during leisure hours and does not prevent active participation in sports and games To this group were assigned among others, children who could attend school and take part in games and athletics

Group II Partial restoration — the patient has a job but is not seldom forced to be absent owing to stump distress, implying that the amputation restricted both working and leisure activity To this group were assigned housewives who continued to keep house except for heavy chores

Group III Self care plus — the patient is able to do part time work or light work with special transport arrangements or minor modifications to ancillary equipment If such favourable circumstances did not apply or the patient was too unintelligent to manage a light job, he would be unemployable The patient is exhausted by appreciable leisure activity and has to arrange his whole life towards resting when not at work The patient can unaided carry on all activities of daily living To this group were assigned many elderly subjects who could care for themselves without outside help

Group IV Self care minus — the patient is to be regarded as a disability pensioner No patient in this group was at work They required assistance to apply and remove the prosthesis They spent all their time doing the most essential household chores but had to have groceries and other purchases brought in by others

Group V Domestic care — the patient is confined to his bed or wheelchair and cared for at home These patients required considerable assistance and required a full time attendant

Group VI Institutional care — the patient has been in hospital or other institutions since the amputation The majority of patients in this group were bed ridden

No distinct lines of demarcation separate these groups If, at the confrontation with an individual patient there was doubt as to which group the patient belonged to the principle was adopted of assigning him to the worse group Considering that the sole aim of this classification was to provide a schematic picture of the amputee s situation, this rough estimation was deemed adequate

The sociomedical function was assessed a year after amputation for patients in the 331-Series and at the time of the follow up examination for patients in the 133 Series, apart from patients over statutory pensioning age whose sociomedical function during their working years was assessed retrospectively A consequence of this was that very few of the older amputees in the 331 Series were assigned to sociomedical function groups I or II where it was required that the patient should be employed Hence assignment to group III must be considered a good result for such older patients in the 331 Series The patients in groups I—III were all able to care for themselves unlike those in groups IV—VI who could not cope unaided with the activities of daily living

As the sociomedical function of the majority of older patients in the 331 Series assigned them to the groups of domestic or institutional care it was deemed convenient to regard the patients in groups I and II as belonging to a single category called Restoration to combine groups III and IV into the single category Self care and to combine the categories Domestic care and Institutional care into Disabled

In the 133 Series the patient s occupation or trade after amputation was related to his job before it The patients were asked whether they had received vocational training or been reeducated Their present work was evaluated as to the degree of labour involved and rated as light moderate or heavy The economic status of the patients in the 133 Series was judged from their gross annual income averaged over the years 1960—1962 and from whether they had received or were receiving any form of monetary compensation for their disablement The marital status and dwelling condition of these patients were also taken into consideration

THE 331 SERIES

Unilateral amputees younger than 60 years

The functional classifications of the 52 patients surviving at least a year after the last amputation are given in Table 9 1 The 5 patients who required domestic or institutional care had the same amputation cause peripheral obliterative arteriosclerosis One of them had been treated for several years preoperatively in various hospitals All of them were disabled by additional handicaps namely severe cardiac disease in 4 cases and mental retardation in one case As the time of amputation 4 of the 5 disabled patients were in the 50—59 years age group

Half the 12 Self care patients had additional handicaps Two thirds had amputation ages of 50—59 years Half were below knee amputees

Sociomedical function	No	
I 10 "Restoration II 25	35	67 3
III 8 Self care IV 4	12	23 1
V 2 Disabled VI 3	5	9 6

Table 9 1 Distribution of sociomedical function in unilateral amputees below 60 years old in the 331 Series

The amputation cause was peripheral obliterative arteriosclerosis in half the patients and tumours or accidents in the other half

The Restoration group of 35 patients was characterized by a low frequency of additional handicaps which were present in 3 patients only Three fifths were below knee amputees The amputation causes comprised 22 accidents 6 tumours 3 Burger s disease 2 congenital pseudarthrosis of the tibia, 1 peripheral vascular disease and 1 aneurysm

As appears from Table 9 2 the proportion capable of working among these patients in the amputation age groups below 60 years decreased with rising amputation age While 5 of 7 in the 40—49 years group were able to work, only 8 of 20 were working in the 50—59 years group

Among the 16 patients subjected to amputation for peripheral vascular disturbances, 5 returned to work The amputation cause was Burger s disease in 3, unspecified vascular disease in 1 and aneurysm of the popliteal artery in 1 of the 5 who went back to work None of the 3 diabetic gangrene amputees were able to work

Age group	No	Restored or working
50—59	20	8
40—49	7	5
30—39	11	9
20—29	6	5
10—19	5	5
< 10	3	3

Table 9 2 Frequency of restoration among 35 unilateral amputees below 60 years of age and surviving at least 1 year after last amputation in the series of 331

Unilateral amputees older than 60 years

The functional results for the 108 unilateral amputees are given in Table 9.3. 53 received institutional care and 25 domestic care, altogether 78 patients or 72 per cent. Preoperatively 15 of the 78 had been treated in hospital for at least 6 months, the majority for several years, 6 in a hospital for chronics, 7 in mental hospital and 2 in a home for sociomedical cases. The amputation had not affected the care requirements of these preoperatively disabled. 17 of 78 were subjected to amputation in 1961, leaving 61 postoperative disabled with observation periods of at least five years. Of the latter 21 survived at least four years, receiving institutional care throughout this period, 5 died during the fourth postoperative year and the remaining 35 during the second and third years.

Table 9.3. Sociomedical function of 108 amputees from the 331 Series over 60 years old and surviving at least 1 year after last amputation

Sociomedical function	Men	Women	Total	%
I 0 Restoration II 2	2	0	2	1.9
III 10 Self care IV 6	16	12	28	25.9
V 25 Disabled VI 53	42	36	78	72.2

The functional results after elimination of the preoperatively disabled were distributed as shown in Table 9.4. 30 patients or 32 per cent of these 93 elderly unilateral amputees were in functional groups I—IV. After the amputation the remaining 63 or 68 per cent were disabled, 38 of them spending the rest of their lives in hospital and 25 receiving domestic care most of the time.

The 2 patients who had returned to work both underwent above knee amputation for non diabetic obliterative arteriosclerosis. One of them, a bachelor, was 66 and the other a married man 60 years of age at the time of amputation. The former returned to a sedentary workshop job, the latter worked as a precision machinist.

Table 9.4. Sociomedical function of 93 amputees from the 331 Series over 60 years old and surviving at least 1 year after last amputation prior to which they did not receive institutional care

Sociomedical function		No	%
Restoration	I—II	2	2.[illegible]
Self care	III—IV	28	30.1
Disabled	V—VI	63	67.7

The 28 patients in the "Self care" category included 9 with additional handicaps. The majority were 60—69 years of age at the time of amputation. All but one were prosthesis walkers.

Particulars about the 78 requiring institutional or domestic care are given in Table 9.5. This group was characterized by a high incidence of additional handicaps, predominantly circulatory disturbances in the intact leg. Many had multiple handicaps, although the table specifies only the most disabling disease. Additional handicaps were present in 63 patients or 81 per cent. The majority of the disabled were 70—79 years old at the time of amputation. 16 were able to walk with a prosthesis. There was a

Table 9.5. Distribution of amputation ages, causes and levels and of additional handicaps among 108 amputees over 60 years in the 331 Series

	Amputation age group year	No.	Amputation cause		Amputation level		Additional handicaps	
Restoration I—II 2 patients	60—69	2	Peripheral vascular disease	2	Above knee	2		0
Self care III—IV 28 patients	60—69	15	Peripheral vascular disease	23	Above knee	11	Circulatory disturbance in intact leg	2
	70—79	10	Accidents	3	Below knee	17	Strokes	2
	80—89	3	Tumours	2			Cerebral arteriosclerosis	2
							Marked loss of vision	2
							Residual state after fracture of femoral neck	1
								9
Disabled V—VI 78 patients	60—69	28	Peripheral vascular disease	73	Above knee	46	Circulatory disturbance in intact leg	23
	70—79	38	Tumours	3	Below knee	32	Cardiac distress	13
	80—89	12	Frost bite	1			Cerebral arteriosclerosis	9
			Accident	1			Hemiplegia	6
							Mental disease	6
							Joint disease	2
							Blindness	1
							Nephropathy	1
							Myelomatosis	1
							Oesophageal stenosis	1
								63

preponderance of single individuals, 56 patients as against 22 with a living spouse

The proportion of disenabled rose with advancing amputation ages. Not counting the preoperatively disabled the distribution of disabled amputees within amputation age groups becomes 22 or 56 per cent of those ages 60—69 years, 31 or 76 per cent of those aged 70—79 years and 10 or 77 per cent of those aged 80—89 years

Bilateral amputees

Table 9 6 presents data on the sociomedical function of 31 bilateral amputees. The two patients capable of working were bilateral below knee amputees and in good health otherwise. The "Self care" group was composed solely of gangrene amputees. The disabled were characterized by a high incidence of additional handicaps being present in 16 patients of 25. The amputation cause in this group was gangrene in all except one who underwent bilateral above knee amputation for metastasizing sarcoma

Table 9 6 Distribution of amputation ages causes levels and additional handicaps among 31 *bilateral amputees in the 331 Series*

	Amputation age group years No	Amputation cause	Amputation level	Additional handicaps
Restoration I—II 2 patients or 7	50—59 2 60—69 2	Buergers disease 1 Accident 1	Below knee 2	0
Self care III—IV 4 patients or 13	50—59 2	Diabetes 2 Arteriosclerosis 1 Embolism 1	Above knee 1 Above and below knee 2 Below 1	Cardiac distress 3
Disabled V—VI 25 patients or 81 %	10—19 1 50—59 1 60—69 7 70—79 12 80—89 4	Diabetes 18 Arteriosclerosis 6 Tumour 1	Below knee 8 Above knee 11 *Above and below* knee 6	Stroke 4 Senile mental insufficiency 4 Cardiac distress 4 *Loss of vision* 2 Nephrosis 1 Rheumatoid arthritis 1 16

Frequencies of institutional and domestic care in different years

Table 9 7 shows how the disabled patients over 60 years at the time of unilateral amputation were distributed in the years 1947—1956 and 1961 There was no change in the proportion disabled among the total number of new amputees in any of the periods

Period	No	Disabled	
		No	
1947 – 1948	10	8	80
1949 – 1950	15	12	80
1951 – 1952	17	10	59
1953 – 1954	18	13	72
1955 – 1956	25	19	76
1961	23	16	70

Table 9 7 Frequency of disabled during different periods among 108 amputees over 60 years of age of the 331 Series

As the number of elderly amputees is rising all the time we have to face the fact that the absolute number of diseabled also will grow Let this be illustrated by the sombre picture that emerges when we scrutinize the functional results achieved by the 74 patients subjected to amputation in 1961 At the end of February 1963 43 of them were known to be dead and the 31 others or 42 per cent had been followed up and found alive Up to two years after the amputation 19 of the survivors were still in hospital The other 12 were living in their homes and 8 of these had to be regarded as chronic domestic care cases Only 1 of the remaining 4 was back at work thanks to large contributions from public funds to finance retraining for a more suitable job part payment for a car and the cost of driving lessons another had great difficulties in locomotion owing to a poorly fitted prosthesis another walked with his prosthesis despite a large wound on the stump and the last, a female prosthesis walker, was unable to work because of depression In sum only one of the 74 patients subjected to amputation in 1961 was back at work about two years postoperatively, and no less than 27 of the 31 then surviving were chronically disabled 19 of the 27 requiring institutional care and 8 domestic care

Case reports

The problems posed by and facing the elderly amputee with clinically and sociomedically impaired functional ability will now be exemplified

by reports of four cases in which the author visited the patient's home and made supplementary environmental observations

Patient 185 a widow born November 6 1878 The patient had senile diabetes since the mid 1950s and in the autumn of 1955 the right great toe became gangrenous She was treated at Lkmınska Sjukhuset 17/?—31/3 1956 The great toe amputation proved ineffective so on the 17th March 1956 the right leg was amputated above the knee She received a prosthesis but could not learn to use it owing to senile mental insufficiency Since discharge from hospital she was given domestic care by the geriatric nursing service for two hours daily and by daughters taking turns watching over her day and night She was visited December 30 1962 Her home was a flat on the 2nd floor without modern conveniences or toilet There was no central heating The patient sitting in a wheelchair without prosthesis was completely disoriented as to time and place talking incoherently A daughter said she required constant attention She was incontinent of urine and never left the flat

Patient 4 5 male born February 6 1887 married The patient a former tramline worker had a hemiplegia of the right side in 1957 and 1958 Towards the end of December 1960 *gangrene of the right foot set in and on the 8th February* 1961 the patient was admitted to Surgical Department II Sahlgrenska Sjukhuset where the right leg was amputated above the knee for non diabetic gangrene on the 9th March He was transferred to a hospital for chronics the 29th March 1961 and treated there until the 16th November 1962 The amputation wound healed secondarily a prosthesis was fitted and he was given gait training for a considerable period When visited on the 1st March 1963 he was found to live in a semi modern flat on the second floor with a toilet on the landing There was no elevator He was cared for by his wife who was 70 years old and had a painful back He was sitting in a chair with the prosthesis on He managed to walk round a table with the greatest difficulty supporting himself with one hand on the edge of the table He suffered from total afasia and hemiplegia of the right side His wife had to dress him and helped to apply and remove the prosthesis He had moreover to be fed and needed assistance in using the toilet His wife said he used to sit in his wheelchair most of the day He never left the flat because he could not get down the stairs The patient required constant attention

Patient 410 male born June 26 1880 married Had been operated on in 1956 for cancer of the anus Dry gangrene of the 2nd and 3rd toes on the left foot developed in January 1961 He was treated in the Surgical Department Sahlgrenska Sjukhuset 24/1—14/4 1961 where the left leg was amputated above the knee because of the gangrene on the 23rd February the wound healing by the second intention He was admitted to the Orthopaedic Department and treated there 8/9—26/9 1961 where he was fitted with a prosthesis and given gait training The patient became able to take a few steps with the aid of crutches For practical purposes however the patient had to be regarded as a wheelchair case In December 1961 the right foot began to give trouble Admitted to a hospital for chronics 4/11—8/2 1963 he underwent below knee amputation of the right leg on the 29th November 1962 The patient visited the 1st March 1963 lived in a semi modern 2nd floor flat with his sickly wife who was 79 years of age A geriatric nurse helped the couple for two hours daily but otherwise no one looked after them The patient was dressed and sitting in a wheelchair with a badly fitting above knee prosthesis on the left side and no prosthesis on the right side He was well oriented and able to describe his case competently He seemed well adjusted to his situation His wife however had to dress and wash him every day Had never left the flat since coming home from hospital

Patient 429 a spinster born December 29 1873 She was admitted to Surgical Department II Sahlgrenska Sjukhuset 25/8—12/10 1961 with onset of non diabetic gangrene of right great toe in July 1961 A below knee amputation was performed the 13th September Extensive necrosis postoperatively necessitated above knee reamputation the 20th September Visited the 1st March 1963 She was living with an elderly sister in a semi modern detached house at the top of a steep *hill and with a long flight of steps* leading to the entrance The patient a large and obese woman with extensive oedema on the stump was lying in bed with an indwelling catheter She was completely disoriented as to time and place and had never been given a prothesis The sister said she could sit up in a wheelchair for short periods but the sister had to be helped by a geriatric nurse

Frequencies of institutional and domestic care in different years

Table 9 7 *shows how the disabled patients over 60 years at the time of* unilateral amputation were distributed in the years 1947—1956 and 1961 There *was no change in the proportion* disabled *among* the total number of new amputees in any of the periods

Period	No	Disabled	
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Patient 405 male born February 6 1887 married The patient a former tramline worker had a hemiplegia of the right side n 1957 and 1958 Towards the end of December 1960 gangrene of the right foot set in and on the 8th February 1961 the patient was admitted to Surgical Department II Sahlgrenska Sjukhuset where the right leg was amputated above the knee for non diabeti gangrene on the 9th March He was transferred to a hospital for chronics the 29th Mar h 1961 and treated there until the 16th November 1962 The amputation wound healed s condarily a prosthesis was fitted and he was given gait training for a considerable period When visited on the 1st March 1963 he was found to live in a semi modern flat on the second floor with a toilet on the landing There was no elevator He was ared for by his wife who was 70 years old and had a painful back He was sitting in a chair with the prosthesis on He managed to walk round a table with the greatest difficulty supporting himself with one hand on the edge of the table He suffered from total afasia and hemiplegia of the right side His wife had to dress him and helped to apply and remove the prosthesis He had moreover to be fed and needed assistance in using the toilet His wife said he used to sit in his wheelchair most of the day He never left the flat because he could not get down the stairs The patient required constant attention

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The cases reported in the foregoing are all typical of patients classified as requiring domestic care The patients in these four cases had in common the complete isolation in a dwelling and the need for attention practically round the clock None could have lived at home were it not for the considerable efforts of the geriatric nursing staff and the great sacrifices of relatives who were obliged to discontinue or severely limit their income-producing activities All were handicapped by two or more intercurrent diseases and each of these tended to inhibit function The social status of the patient requiring domestic care not infrequently prevents his effective rehabilitation The patient may be single or have an old and frail spouse who is too weak to assist the amputee even with the simplest tasks Or as often is the case, the amputee s dwelling may be without any modern conveniences and in bad repair making it anything but suitable

Factors influencing sociomedical function

The leg amputee s sociomedical function is governed by his physical condition mental status and social background

In the present context, the term physical condition includes general health stump condition and for the sake of simplicity clinical function Classification of the patients in the several groups of sociomedical function in regard to the distributions of amputation age, amputation cause, additional handicaps and clinical function discloses that patients less than 60 years of age returned to work with diminishing frequency the higher their amputation age Among patients over 60 years of age rising amputation age increased the proportion requiring institutional or domestic care Apparently, however, the rising frequency of additional handicaps in elderly amputees seems to be responsible for this result rather than rising amputation age Among the younger patients those between 40 and 60 years of age had the worst sociomedical function In this age group the dominant cause of amputation was peripheral vascular disease, a systemic condition involving not only the vessels in the lower extremities but also those in the brain, heart, etc. The rising frequency of additional handicaps with advancing age was probably responsible for the falling sociomedical function The sociomedical function of traumatic amputees was good for the majority of these patients were young and not otherwise handicapped *The sociomedical function was worse among gangrene amputees* because diseases accompanied by gangrene also gave rise to additional handicaps In all age groups additional handicaps usually made the sociomedical function worse Whereas good clinical function was a *sine qua non* for good sociomedical function good sociomedical function was not necessarily a consequence of good clinical function as bears witness the fact

that the group of amputees older than 60 ye[illegible] [illegible]itutional or domestic care included 16 prosthesis walke[illegible]

Here attention was paid merely to one of t[illegible] the patient's mental status namely manifest mental dis[illegible] form of senile mental insufficiencies and oligophrenia [illegible] e included among so-called additional handicaps Stud[illegible] e of mental status on the amputee's sociomedical funct[illegible] account the patients morale Analysis of this factor howe[illegible] fall outside the scope of the present investigation

The marital status of the patient was the o[illegible] component of the amputee's social environment considered in the p[illegible] investigation but his sociomedical function might be influenced by a variety of other social factors Elderly amputees with a living relative had better sociomedical function than those with no one to help them Among the 93 amputees not requiring institutional or domestic care preoperatively the frequency of those with no living spouse or other relative differed significantly on the 2 5 per cent level from the lower frequency of those with such a person in their environment The ratio of postoperative disablement to postoperative non disablement among single amputees was about 4 1 while the corresponding ratio for amputees with a spouse or other relative was about 1 1 This appears from Table 9 8

Table 9 8 Frequency of disabled among single and married unilateral amputees in the 331 Series over 60 years old and not receiving institutional care prior to amputation

Sociomedical function	Marital status	
	Single	Married
Restoration + Self care	11	19
Disabled	42	21
Total	53	40
$\chi^2 = 5.0$ d f = 1 $0.01 < P < 0.0$[illegible]		

THE 133 SERIES

Information on the classification of these patients according to their sociomedical function is presented in Table 9 9 The Full restoration group included the highest proportion of these 133 patients The majority of the 93 fully restored patients — 67 patients or 72 per cent — were under 30 years of age at the time of amputation Accidents constituted the most common cause of amputation with 58 patients or 62 per cent The

Sociomedical function		No	%
Full restoration	I	93	70
Partial restoration	II	24	18
Self care plus	III	13	10
Self care minus	IV	3	2
Total		133	100

Table 9 9 Sociomedical function in the 133 Series

amputation level was below the knee for the majority, namely 65 patients or 69 per cent One or more additional handicaps were present in 12 patients or 13 per cent While 65 patients or 70 per cent were married and had a living spouse, the remaining 28 patients were bachelors or spinsters

The 24 patients in the Partial restoration group were also for the most part young, 16 of them being less than 30 years of age at the time of amputation The dominant amputation cause was trauma with 19 patients Above-knee amputees numbered 13 Additional handicaps were present in 12 patients and lastly 20 were married and had a living spouse

The Self care plus group of 13 patients included 8 with an amputation age over 30 years disproportionately few traumatic amputees, 6 above-knee and 7 below-knee amputees, 10 of 13 with additional handicaps and 4 married and 9 single patients

For the three patients in the Self care minus group fairly full data will be supplied in the form of case reports at the end of this chapter, page 91

The incidence of additional handicaps tended to rise with decreasing sociomedical function Conditions included among the additional handicaps in the 133 Series are set out in Table 9 10

* * * * *

The sociomedical function as a whole was better in this series of 133 patients than in the series of 52 patients less than 60 years of age subjected to leg amputation in Gothenburg in the years 1947—1956 and 1961 Whereas 88 per cent of the patients in the 133 Series were assigned to the restoration group the corresponding figure for the sample of 52 patients from the 331 Series was 67 per cent The difference was due to the fact that the 52 patients included a high proportion of gangrene amputees and peripheral vascular disease is consistently associated with impaired sociomedical function Conversely very few of the amputees in the 133 Series had vascular disease as the cause of amputation This was

because those gangrene amputees had died who otherwise would have been included in this series The patients in the 133 Series in the first place provide us with an impression of the traumatic amputee s sociomedical function once the difficulties of the first few years have been overcome No patient required institutional or domestic care while the aforementioned 52 patients from the 331 Series included 10 per cent such cases all with peripheral vascular disease as the cause of amputation The prognosis for gangrene amputees is discouraging and that seems to be so whether the patient s amputation age is over or under 60 years Gangrene amputees younger than 60 years had their ability to work destroyed or greatly impaired and gangrene amputees older than 60 years in most cases required institutional or domestic care

Table 9 10 Additional handicaps in the 133-Series

Additional handicaps	No
Arteriosclerotic heart disease	8
Degenerative arthritis of hip and knee joints	7
Circulatory disturbance in intact leg	5
Back pain	4
Cerebral haemorrhage	2
Mental deficiency	2
Stump eczema	2
Marked loss of vision	2
Thyreotoxicosis pulmonary insufficiency rheumatoid arthritis peptic ulcer arm amputees one of each	5
Total	37

Distribution of occupations

Occupations represented among the patients in the 133 Series are specified in Table 9 11 together with an indication of the type of labour involved The occupations of all the patients are included for retired patients the occupation before retirement The preoperative and postoperative distributions of heavy moderate and light labour are shown in Table 9 12 A change to lighter work was made by 41 of the 51 who had heavy work preoperatively The No occupation group comprised children and adolescents subjected to amputation before starting work or while attending school All below working age at the time of amputation were trained for light or moderately heavy work

Sociomedical function		No	
Full restoration	I	93	70
Partial restoration	II	24	18
Self care plus	III	13	10
Self care minus	IV	3	2
	Total	133	100

Table 9 9 Sociomedical func tion in the 133-Series

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Table 9.10. Additional handicaps in the 133-Series.

Additional handicaps	No.
Arteriosclerotic heart disease	8
Degenerative arthritis of hip and knee joints	7
Circulatory disturbance in intact leg	5
Back pain	4
Cerebral haemorrhage	2
Mental deficiency	2
Stump eczema	2
Marked loss of vision	2
Thyreotoxicosis, pulmonary insufficiency, rheumatoid arthritis, peptic ulcer, arm amputees one of each	5
Total	37

Distribution of occupations

Occupations represented among the patients in the 133-Series are specified in Table 9.11 together with an indication of the type of labour involved. The occupations of all the patients are included, for retired patients the occupation before retirement. The preoperative and postoperative distributions of heavy, moderate and light labour are shown in Table 9.12. A change to lighter work was made by 41 of the 51 who had heavy work preoperatively. The "No occupation" group comprised children and adolescents who came to amputation before starting work or while attending school. All who were of working age at the time of amputation were trained for moderate or light work.

Sociomedical function		No	%
Full restoration"	I	93	70
Partial restoration	II	24	18
Self care plus	III	13	10
Self care minus	IV	3	2
	Total	133	100

Table 9 9 Sociomedical function in the 133-Series

amputation level was below the knee for the majority namely 65 patients or 69 per cent One or more additional handicaps were present in 12 patients or 13 per cent While 65 patients or 70 per cent were married and had a living spouse, the remaining 28 patients were bachelors or spinsters

The 24 patients in the Partial restoration group were also for the most part young 16 of them being less than 30 years of age at the time of amputation The dominant amputation cause was trauma with 19 patients Above-knee amputees numbered 13 Additional handicaps were present in 12 patients and lastly 20 were married and had a living spouse

The Self care plus group of 13 patients included 8 with an amputation age over 30 years disproportionately few traumatic amputees, 6 above-knee and 7 below knee amputees 10 of 13 with additional handicaps and 4 married and 9 single patients

For the three patients in the Self care minus group fairly full data will be supplied in the form of case reports at the end of this chapter page 91

The incidence of additional handicaps tended to rise with decreasing sociomedical function Conditions included among the additional handicaps in the 133 Series are set out in Table 9 10

* * * *

The sociomedical function as a whole was better in this series of 133 patients than in the series of 52 patients less than 60 years of age subjected to leg amputation in Gothenburg in the years 1947—1956 and 1961 Whereas 88 per cent of the patients in the 133 Series were assigned to the restoration group the corresponding figure for the sample of 52 patients from the 331 Series was 67 per cent The difference was due to the fact that the 52 patients included a high proportion of gangrene amputees and peripheral vascular disease is consistently associated with impaired sociomedical function Conversely very few of the amputees in the 133 Series had vascular disease as the cause of amputation This was

provided vocational training for 14 but 10 of the latter were unable to make a living at their new trade Before undergoing amputation many of the patients had jobs associated with considerable accident risk For example, 12 able seamen sustained circular injuries of the lower extremities from wire ropes or cables The second largest occupational group was railway and tram workers with 9 patients who were involved in accidents while at work

Economic status

When the patients were followed up and asked whether the economic situation was disturbing them, 10 patients or 8 per cent answered in the affirmative namely 8 men and 2 women all of whom were of working age The annual income, averaged over the years 1960—1962 was less than 5000 kronor for all of these patients Social service grants were paid to 2 and no less than 6 of these 10 patients had been re-educated at the State s expense The latter 6 patients included 3 who were unable to find a job owing to structural changes in the employment market, and the other 3 were workshy The last four with economic difficulties were unable to work for medical reasons advanced arthrosis of the hip joint in 2 cases and heart disease in 2 cases

Payments from public or private insurance companies were enjoyed by 60 patients or 43 per cent of the 133 The payments were made in the form of annuities payable quarterly of monthly to 44 patients A lump sum had been given to 7 and a 100 per cent disability pension was paid to 9 patients The 9 patients receiving such pension all had additional handicaps heart disease in 2 arthrosis of the hip or knee joints in 3 hemiplegia in 1, oligophrenia in 1, circulatory disturbance in the intact leg in 1 and lastly, one with an arm amputation

The households the 133 patients came from possessed a car in 42 cases or 32 per cent

Men of working age suffer a loss of income from prolonged illness or disability In an attempt to make an unbiassed assessment of the leg amputee s earning power the gross income of 84 patients in the 133 Series was analyzed These comprised all men of working age except 3 — a technologist a chef and an electrician — about whom no satisfactory information was obtained When interviewed all the 84 said they were working full time and had no financial problems Income specifications for the years 1960—1962 were supplied by the internal revenue office Random fluctuations were eliminated by averaging the income over these 3 years Table 9 13 *presents the distribution by income of these 84 patients* The

Income 1 000 kronor	No
< 4	14
4 – 8	10
8 – 12	15
12 – 16	22
16 – 20	16
20 – 24	6
> 24	1
Total	84

Table 9·13 Mean annual income 1960—1962 of 84 male amputees between 16 and 67 years of age from the 133-Series

median income, after taking the average for the years 1960—1962, was 12.200 kronor per year. In Gothenburg the median income of men aged 25—66 years averaged over the years 1960—1962 was 16 620 kronor. 10 of the patients had earned nothing in at least one of the three years, while 5 of them had earned nothing in any of the years. 4 of these 10 patients were included among the aforementioned patients with economic problems. The other 6 admittedly had a small income, in most cases solely a small pension, but were satisfied with their financial situation. Among those without income in 1960—1962, 5 could be described as vagrants: 1 was oligophrenic, 1 had grave thyreotoxicosis, 1 suffered from hemiplegia and 2 had pronounced arthrosis of the hip joint. 3 of the 5 vagrant-like individuals claimed to have an entirely satisfactory life on their pension and 2 of the 5 were suspected chronic drunkards. None of the 10 patients without income during at least one of the 3 years was in economic difficulties solely because of the amputation.

In studying the leg amputee's social status, the distinction between cause and effect may sometimes be difficult to make. 2 patients in the 586-Series and 1 in the 133-Series actually were subjected to amputation as a direct result of their antisocial way of life. When drunk one of them fell asleep across the railway track and was run over by a train, his injuries necessitated traumatic amputation; another who used to sleep under tarpaulins in the harbour froze a foot so severely one cold night that amputation for frostbite became unavoidable; the third rode a stolen motorcycle at top speed right off the road and became a traumatic amputee. These three patients have remained sociopaths despite repeated medical and social attempts to rehabilitate them.

Marital status and dwelling standards

Of the 133 patients 90 were married and 72 couples had children 37 of the rest were unmarried and the last 6 were divorced or widowed As mentioned the Full restoration group comprised 65 married and 28 single patients Conversely the Self care plus group included 9 single and 4 married patients while the Self care minus group was composed of 2 single and 1 married patient

Data on dwelling standards was supplied by the patients or local officials in their part of the city, while corresponding information for Gothenburg as a whole was obtained from official Swedish statistics By way of comparison it may be mentioned that in 1960 81 per cent of all Gothenburg flats or dwelling units had central heating and 75 per cent had a private toilet Modern dwellings defined as flats or detached houses with central heating as well as toilet and bath were available to 81 patients or 61 per cent semi modern dwellings with shared bath and toilet to 26 patients or 20 per cent and unmodern dwellings with dry toilets and not central heating to the remaining 26 patients or 20 per cent This suggest that the dwelling standards of the 133 leg amputees did not deviate appreciably from the average for Gothenburg The complaint made about dwellings were due to such things as absence of modern conveniences or dissatisfaction with the neighbourhood etc The majority of the blocks of flats had no lift No patient thought that his state of being an amputee gave rise to any problems in his current dwelling

Case reports

The three patients in the Self care minus group had the following histories

Patient 79 a married man born May 31 1897 His diabetes controlled by insulin commenced in 1929 He worked as a points operator with the Swedish Railways until 1951 when he was subjected to amputation of the right leg below the knee for diabetic gangrene He was granted a disability pension in the same year as the amputation He suffered from cardiac disease and nephroretinopathy He was blind on one eye During the follow up examination the patient was able to walk with a moderate limp of the right leg and a cane in the left hand Since the year of the amputation the patient had the last few years the right hand had become paralyzed This couple was childless Lived in a modern flat with no financial problems

Patient 112 a bachelor born February 8 1916 who grew up in a Children s Home He was declared legally not accountable for a criminal offence on psychiatric grounds Was involved in a motorcycle accident in 1950 which necessitated amputation above the knee of the right leg He worked in a laundry at the time and was postoperatively re educated as a mechanic Repeated attempts to find the patient suitable employment were unsuccessful owing to the patient s ingrained distaste for work of all kinds When the patient was seen on the 16th May 1962 he could walk with a moderate limp on the right and required no cane His above knee prosthesis with suction socket fitted well and he was living in an unmodern flat he did no work as he was financed by the social services

Patient 121 a bachelor born March 28 1912 was treated at the age of 1 year for congenital dislocation of the hip Femoral osteomyelitis during ch ldhood considerably shortened the left leg Hence an arthrodesis of the knee and below knee amputation were carried out at the age of 17 years The stump measured from the sciatic tuberosity was 31 centimetres long so he was fitted with a normal above-knee prosthesis with triangular socket and suspension braces Trained with state grants he became a tailor At the follow up examination on the 16th March 1962 it was found that the patient had been receiving a disability pension for some years He had considerable difficulties in walking Aided by a cane he could walk with a rolling gait a maximum of 100 yards Then movements and weight bearing in the hip joints became unendurably painful and forced him to rest Obesity and an incisional hernia were additional handicaps He lived alone in a modern flat and did about 2 hours work daily but was in strained financial circumstances A geriatric nurse came to help him twice weekly

The amputation was a contributory factor to difficult situation of these patients although additional handicaps were mainly responsible for the reduced sociomedical function Quite apart from the amputation these additional handicaps would by themselves impose major restrictions on the patient s ability to work Indeed the second patient s psychopathy had prevented him from doing much work even before the amputation

CHAPTER 10

Discussion

Any conclusions that may be drawn from the foregoing in regard to the frequencies of leg amputees of different types and at different times are valid speaking strictly only for the population of Gothenburg and its immediate neighbourhood Yet it seems probable that this population is representative of a modern urban population in Sweden or a comparable country A series of amputees collected at a rural hospital would perhaps have yielded somewhat deviating results with respect to the type and incidence of accidents leading to amputation farming not infrequently gives rise to severe fractures and soft tissue injuries that necessitate amputation

The surgeon s criteria for amputation will unavoidably to some extent be a product of the local and secular environment of the hospital in which he is working at the time of the operation Hence any far reaching conclusions drawn from the results presented here must not be taken too literally The rate of amputation will be affected by changes in the age distribution of the population by altered morbidity of conditions requiring amputation and by revisions of the indications for amputation

Most of the demonstrated increase in the amputation rate among subjects older than 60 years at the time of amputation can presumably be accounted for by a shift towards higher ages in the population during the years considered here There was a large difference in amputation rate between consecutive age groups over 60 years For example an octogenarian runs five times as great a risk of being subjected to amputation as a person in his 60 s

A further contribution to the amputation rate increment could come from a rise in the incidence of those peripheral vascular diseases which actually make amputation imperative This is suggested not only by the demonstrated rise in amputation rate over the period studied in the age groups 70—79 and 80—89 years but also by the growing number of gangrene amputees Perhaps one could say that currently a higher pro

portion of senior citizens become potential victims of amputation causing peripheral vascular diseases than their forefathers did Changes in the age distribution of the population over 70 years of age might be responsible even for the observed amputation rate increase within the 70—89 years age group The risk of becoming an amputee must rise appreciably between the ages of 71 and 79 years considering that the risk of having a leg amputated was twice as high over 80 years of age as at 70—79 Another possibility that suggests itself is that in the good old days more people never reached the amputation risk zone because they died of their generalized vascular disease before it had advanced to that stage As the years go by the longevity of elderly people with severe vascular disturbances is probably rising steadily which of course brings with it an increase in the number of persons whose feet become gangrenous and have to undergo amputation

It has been shown that the amputation rate remained constant from 1947 to 1954 and only then began to rise That changes in morbidity and in the age distribution of the population could be the whole explanation for this abrupt rise in amputation rate seems most unlikely It is not improbable that changed indications for amputation may have contributed to the greater amputation rate Surgeons have also acquired a more active interest recently as to the role of surgery in the geriatric sector This means that amputations are performed on elderly persons who formerly might have been treated conservatively It could be that the person who died of gangrene in the past nowadays is subjected to amputation and before long dies of its sequels The art of vascular surgery — a speciality among other things dealing with peripheral reconstructive surgery designed to prevent or limit amputation — has done much and will probably do more to keep the amputation rate from rising by means of procedures like embolectomy transplantation of vessels etc But technical problems tend to beset most new activities so one should not be surprised in the future to see that refinements in technique and stricter delimitation of diagnostic entities may eliminate some patients who now come to amputation and perhaps include others The spreading use of transmetatarsal amputation for diabetic gangrene has probably reduced the number of more proximal amputations for this disease Anticoagulant therapy as a prophylactic measure *also seems to promise a reduction of the number of amputations for* thromboembolism

No increase was demonstrated in the frequency of leg-amputations among persons less than 60 years of age nor among the victims of accidents The frequencies of young leg-amputees and of traumatic amputees have probably been prevented from rising by the trend away from the motor

cycle the improvements in industrial accident prevention and the advances in reconstructive surgery

The age at amputation has shown a tendency to rise in the period 1955—1962 This rise seems likely to be accentuated by the changing age distribution of the population At present all age group of leg amputees below 80 years are comprised of a majority of men During the period 1947—1960 the amputation rate tended to rise more for men than for women and the rise for men significantly exceeded that for women in 1961—1962 The excess amputation rate for men could be caused by the increased morbidity of or a growing male predilection for peripheral vascular diseases of the type requiring amputation However population changes might also be a factor in this difference in amputation rate in crease the number of men in the population is slowly rising and if this trend continues the present preponderance of women over the age of 60 years will diminish and vanish

Among elderly subjects amputation should be regarded as merely one sign of a systemic disease which in the majority of cases ultimately is fatal In such patients amputation is an ill omen for the prognosis and the gangrene should be interpreted as a late or delayed manifestation of the patient s vascular disorder This is borne out by the high incidence of multiple manifestations of vascular disease at the time of the amputation the preponderance of above-knee amputees the difficulty of getting the amputation wound to heal the prolonged postoperative convalescence and the high incidence of amputees requiring institutional and domestic care among the elderly

The manifestations of the vascular disease are just as frequent regardless of whether amputation is carried out for peripheral obliterative arterio-sclerosis with or without diabetes although the amputation age was found to be slightly lower for diabetics than for non diabetics perhaps because diabetes mellitus may be and probably is a summation effect of arterio sclerosis of the major vessels and microangiopathy Apparently subjects with early onset of clinical diabetes as a rule patients below 30 years of age, less often develop gangrene Probably this is merely because such patients die of other vascular complications before gangrene supervenes

The discouraging functional attainments of elderly amputees must be considered in the light of the high frequency of vascular disease often serious and systemic in this segment of the population The elderly ampu tee has used up much of his reserve capacity of physical and mental power and to work at a job or merely to cope with the activities of daily living he is forced to tax his powers to the utmost Rarely however was the ampu tation *per se* the cause of total inability to work among leg amputees

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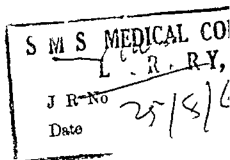
Printed in Sweden
ORSTADIUS BOKTRYCKERI AKTIEBOLAG
GÖTEBORG 1964

ACTA ORTHOPAEDICA SCANDINAVICA
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From the Department of Surgery (Head Prof Olle Hulten M D) University of Uppsala
and the Department of Orthopædics (Head Prof Carl Hirsch M D)
University of Gothenburg Sweden

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Statistical adviser
Gunnar Eklund

Translated by
Catherine G. Sundstrom

Printed in Sweden
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Contents

Introduction

The treatment of intra articular fractures of the os calcis often gives poor clinical results It is commonly known that hardly any present day treatment will consistently produce good function This is particularly so when the fracture involves the subtalar joint Since the fractures are the result of violent trauma and occur in bone consisting mainly of can cellous tissue the damage takes the form of severe comminution Therefore the articular involvement is deleterious and makes reconstruction very difficult or impossible Furthermore in the course of the production of the fracture considerable surrounding soft tissue injury occurs Because of this many advocate a more conservative approach in the treatment believing that the end results will not be different even if the fracture is left to its own fate

The present investigation deals with the anatomical appearance and the clinical end results of os calcis fractures which have been treated by various methods

In order to obtain information about the degree of damage affecting the region of the os calcis studies were undertaken on cadaveric specimens which were subjected to experimentally produced os calcis fractures In these model experiments attempts have been made to study the fracture mechanism the magnitude of the force and the type of fracture related to the position of the foot at the time of injury The lesions have been classified by radiographic and anatomical analysis

Clinically three different series of os calcis fractures treated by either, early mobilization without reduction open reduction with attempts at reconstruction or early triple arthrodesis have been compared with regard to the late end results A statistical analysis of factors which may be signi ficant for the final function of the foot are presented in terms of prog- nostic evaluation

CHAPTER 1

Introduction to the Literature

The literature pertaining to injures and treatment of the os calcis is voluminous In this section it is hoped to profitably give a brief introduction, with mention of the more important works

In 1847 Malgaigne was the first to mention that fractures of the os calcis were compression fractures Schmitt (1896) attempted to evaluate the static fracture force of some ten specimen but no exact data was given the forces were said to vary between 500 and 2500 Kp By his experiments he produced shearing fractures which Baer (1905) confirmed Neither these authors nor Tietze (1908) were able in detail to analyze the effect of different positioning of the foot Tietze however arrived at the conclusion that the type of fracture probably changes to a very high extent according to direction of the dynamic force Some similar experiments have also been done by Paitre & Boppe (1935) and by Aurup (1958)

In the literature concerning the treatment and follow-up results of os calcis fractures many different types of treatment are described These range from immobilization without reduction, closed reduction and to various operative procedures The result and assessments vary considerably in the different series and for these reasons it is difficult to make valid comparisons and conclusions

Immobilization without reduction Felsenreich (1935), Bode (1937) Ahlberg (1940) and Nissen Lie (1946) have all described the management of os calcis fractures utilizing only immobilization but without attempts at reduction

Manual reduction Closed reduction as a method of treatment was used by Cotton & Wilson (1908) McFarland (1937) Herman (1937), Laroyenne & Houot (1944) Page & Mumford (1945), Carothers & Lyons (1952), Wendt (1953) Barnhard & Odegard (1955) and by Steinkohl & Miethaner (1961) This method appears to have many current advocates

Reduction with instruments Several methods are described in the literature Goff (1937) gave a good survey of those used until that date The method generally in use is the technique described in 1929 by Bohler with traction through the tuber of the os calcis and counter traction through the tibia Counter traction through the metatarsal bones was used by Arnesen (1939 and 1958), Holund (1951), Aurup (1958) and by Aars & Bie (1961) Reduction of the depressed fragments by the use of a nail was recommended by Westhues (1934) Burkle-de la Camp (1936), Lauritzen (1947), Zorn (1960) and by Maurer (1960)

Open reduction This principle was initially advocated by the French surgeon Leriche (1922) who was the first to use screws or clamps for the osteosynthesis This was also utilized and described by Simon & Stultz in 1928 and 1930 as well as by Stultz (1935) and Whittaker (1947) Lenormant (1928) and his co-workers were the first to insert bone grafts at open reduction This technique was then independantly described by Palmer (1945 and 1948) who used traction through the tuber during the operation as did Sicard & Mutricy (1934) Since Palmer s account of his method in 1948 this method has come into general use The largest series presented are those of Widen (1954) Good results have later been reported by Essex-Lopresti (1952) Maxfield & McDermott (1955) Allan (1955) Leonard (1957) and Maxfield (1936) Scandinavian reports with the recent use of this method are by Rosendahl-Jensen (1956) and Grewald et al (1961)

Primary arthrodesis VanStockum (1912) seems to be the first one using subtalar arthrodesis as a primary treatment of os calcis fractures Several others have later used this operation in severe os calcis fractures amongst them Wilson (1927) Gallie (1943) Armstrong (1943) Harris (1946 and 1963) Geckeler (1950) Becker (1951) Gollasch (1953) Lindsay & Dewar (1958) Ehalt (1957) Stultz et al (1960) and Hall & Pennal (1960) In some reports the arthrodesis includes not only the subtalar joint but also the joints between the talus and navicular and the calcaneus and cuboid, in other words a triple arthrodesis This method has been advocated among others by Conn (1935) Bankart (1942) Kiaer & Anthonsen (1942) Moberg (1951) Moberg & Erfors (1953) Brattstrom (1953) and Thompson and Friesen (1959)

Early physiotherapy without attempt at reduction One of the first reports given of this type of treatment was by Roberts and Sayle Creer in 1946 Their patients were kept in bed for about two moths and treated with physiotherapy

Essex Lopresti in 1952 followed 70 patients in Roberts and Creer s series and found that 80% were back to work He also found the subjective complaints of the patient to be stationary after 1 5 years In 1952 he compaired the results of early physiotherapy with some other methods of treatment Here he claimed that early physiotherapy was the best treat ment for displaced fractures in patients over the age of 50, and in all those without displacement Bertelsen & Hasner (1952) reported on 23 patients and mentioned some of the advantages of the method including the earlier return to work Day (1950), DeBold & Stimson (1957) Brorson & Rosendahl Jensen (1959) Barnhard (1963) and Kolle Jorgensen (1963) in smaller series found no disadvantages of the method

In material obtained from a Danish insurance company Rosendahl-Jensen in 1956 divided 485 intra-articular os calcis fractures according to the functional results of the different methods of treatment He could not find any statistical difference between those treated by early physiotherapy by plaster of Paris or by any surgical methods The end result for all cases was that about 30% received a permanent disability rating

Charnley recently (1957) has emphasized that very successful clinical results can be attained in those cases where the fracture is not reduced and that most unsuccessful results follow attempts at open reduction

The correlation between degree of displacement and the mobility of the subtalar joint, as well as the correlation between the tuber joint angle and displacement of the fracture was pointed out by Lance Carey & Wade (1963) In a series of 227 cases of intra articular os calcis fractures, 20% of these were treated by early mobilization The author claimed that fractures treated by early physiotherapy did better as to hospital stay, work disability and final prognosis They concluded that better results are obtained by early physiotherapy in those cases were there is no more than moderate displacement of the posterior articular facet

EXPERIMENTAL SECTION

CHAPTER 2

Experimental Os Calcis Fractures on Autopsy Specimens

The os calcis fractures seen clinically usually arise from a sudden blow to the heel This happens in two ways, either a person falls from a height, landing on his heels or the floor explodes under him In both cases the os calcis receives a sudden dynamic force

Experimental technique

In order to study the effect of a sudden force against the heel, experiments have been made on autopsy specimens (fig 1)

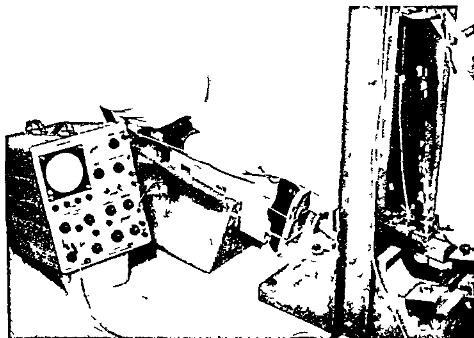


Fig 1 Apparatus for producing experimental calcaneal fractures

For this purposes legs exarticulated through the knee joint at autopsy have been used The preparation was usually tested the same day it was taken or it was stored in a deep-freeze and thawed before the experiments The preparation was fixed in a specially constructed steel retaining stand (A fig 2) The tibial condyles were levelled off in order to fit snugly against the plate (1) on the stand The foot hanging free in the air was fitted with a suitable shoe (2) A wooden plate (3) was attached to the sole and heel of this shoe On the light wooden plate a rubber bumper (4) was fixed An Amsler pendulum type impact machine (B) was used to produce the sudden force On the hammer of this machine a thin tube (5) was mounted with a plate of duraluminum on its end (6) This plate strikes the rubber bumper on the wooden plate at the moment of impact The pendulum and the retaining stand were so placed that the blow hit the leg at right angles to the wooden plate In order to register the forces that act on the specimen, strain gauges were mounted on the tube (5) Through a special trigger device it was possible to register photographically on an oscilloscope (C) the impulses that occured at the moment of impact On the oscilloscope the force will be seen as a function of time (Fig 3) Prior to the experiments a calibration against a known static load was made The result of this procedure was also fed into the oscilloscope giving a known load line parallell to the base line (Fig 3)

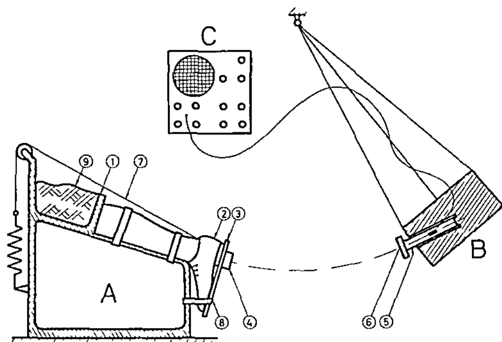


Fig 2 Drawing of the apparatus seen in fig 1

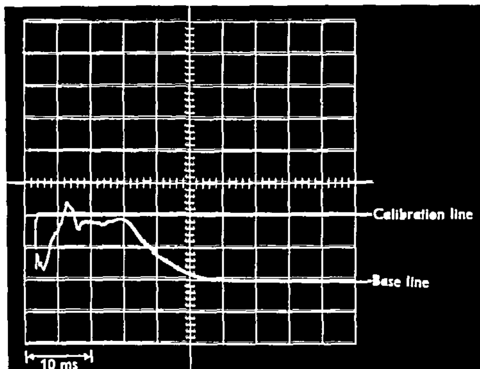


Fig 3 Applied force as a function of time (case no 28)

The achilles tendon was held under tension by a special spring (Fig 2 7) In order to counteract this force a special device (Fig 2 8) was fixed to the anterior part of the foot Through these arrangements the position of the foot could be varied The stand on which the preparation was mounted (Fig 2 9) was given a total weight of 75 kilograms It was placed on the floor but not fixed to it Thus when the pendulum struck the preparation, as mentioned above this stand could move on the ground

The ultimate experimental set up was based on a series of test runs During these it was found, among other things that when the stand was fixed to the floor os calcis fractures occurred of a type, not seen clinic ally The same was true when the pendulum struck an unprotected heel The type of fracture occurring in these latter case was a gross fracture in the plantar aspect of the tuber, with a mosaic pattern Not until the stand was allowed to move freely against ground resistance and the specimen was secured in a shoe and plate did one succed in obtaining fractures similar to the ones seen clinically

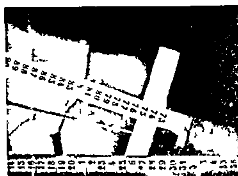
HIGH SPEED
CAMERA
OSCILLOSCOPE
PENDULUM
SPECIMEN

Fig 4 Drawing illustrating the method of high speed photography during impact

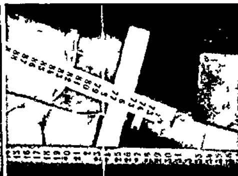
kp mm
1000 40
750 30
500 20
250 10
0
0 5 10 15 20 25 30
t ms
① ② ③ ④

——— Force (kp) as a function of time
——— Compression of specimen (mm) as a function of time
— — — Displacement of retaining stand (mm) as a function of time

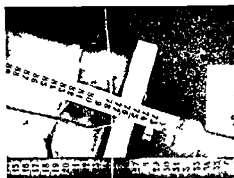
Fig 5 Composite graph showing the relationship between time applied force the degree of compression produced and displacement of the retaining stand (Case No 36)



① Start of impact



② t = 7 4 ms
Force = 865 Kp
Compression of specimen = 16 mm
Displacement of retaining stand = 0 mm



③ t = 12 7 ms
Force = 780 Kp
Compression of specimen = 19 mm
Displacement of retaining stand = 6 mm



④ t = 30 ms
Force = 75 Kp
Compression of specimen = 12 mm
Displacement of retaining stand = 27 mm



Lateral roentgenogram of the fractured specimen

Fig 6 Figures obtained at specific times ① ② ③ and ④ denoted on facing graph The vertical white line across the pictures represents the force as recorded from the oscilloscope

Pre- and post experimental radiograms were taken of the specimens The technique used for these radiograms has been described by Broden 1949 (chapter 4 page 35) Some of the preparations were subjected to a further radiographic analysis with tomography All these specimens were dissected after having been stored in a deep freeze The dissections were made with the specimens still frozen in order not to derange the fracture pattern The dissected preparations were then all photographed

The falling height of the pendulum and thereby its kinetic energy at the moment of impact was varied From the earlier experiments the amount of energy needed to produce fractures of the os calcis were determined It was also established that this variable amount of kinetic energy necessary to produce fractures was due to several factors among those the age and general condition of the skeleton as seen from the roentgeno graphic pictures

The tensional force in the achilles tendon varied between 0—40 kilo grams Within these limits no gross difference in the pattern of the fractures were obtained This tensional force helped to vary the position of the foot in the ankle and subtalar joints without giving it a rigid position

In some experiments the impact was recorded with a high speed camera (type Kodak) with a maximum capacity of 3,000 frames/second (fig 4) This camera was equipped with two objectives at right angles to each other This made it possible to register directly both the impact and the force-time relationship on the oscilloscope It was also possible to determine the amount of compression occurring in the specimen and to study its relation to time and movement of the retaining stand Along the longitudinal axis of the specimen a ruler was mounted A second ruler was fixed on the floor In this way it was possible to visualize the amount of compres sion in the heel and the amount of motion of the stand after the moment of impact In these cases the calibration was fed into the oscilloscope and recorded by the camera on the same film as the following experiment Thus the white vertical line representing the force seen in fig 6 could be evaluated

In figure 5 are shown the curves from such a representative experiment These curves were produced from 70 pictures taken at the speed of 2 100 frames/second In figure 6, four pictures from four different periods of the experiment are shown (marked 1—4 in fig 5) Both from the curves in fig 5 and from fig 3 it is possible to demonstrate a bi phasic course of the force line In the beginning it rises steeply, turns downward for a moment only again to rise, but this time somewhat slower During the first phase most of compression is occuring and probably also the fracture at least to some extent This view is supported by fig 5 and in

this case the second phase probably corresponds to further compression of the bone and to the force displacing the 75 kilogram retaining stand It is possible to interpret from the pictures how the stand is beginning to move during this second phase (fig 5) It is also seen that most of the impact period is spent within 30 milliseconds After the maximum total compression is recorded, some rebound occurs in the soft tissues The re maining deformity will be due to the fracture of the os calcis

Type of experimental fractures

Altogether the final experimental series which could be evaluated com prised of 36 cases The fractures that occured were classified with regard to the antomical appearance as seen on radiograms as well as from anatomical dissections In table 1 are recorded pertinent data from all the final experiments

Based on the results obtained from this experimental investigation it was found possible to classify the fractures on anatomical roentgenological and patho mechanical grounds into four main types The fracture types have also been clossified according to Widen (p 42) and to Palmer (p 43)

Type I (fig 7)

Fractures of type I occurred when the foot was pronated at least 10 degrees and dorsiflexed 5—10 degrees through the talo crural joint The fracture pattern seen in these cases was composed of a main shearing fracture extending from the plantar and medial aspect of the os calcis forward cranially and laterally to just behind the posterior articular facet This fracture runs lateral to the posterior facet into the sinus tarsi which is fragmented

Usually, the os calcis is separated into two fragments, one smaller antero medial carrying all the articular facets and displaced caudal and medial in relation to the second and larger postero lateral fragment

This type of fracture corresponds clinically to group V according to Widen s classification

Type II (fig 8)

Fractures of type II occurred when the foot was in mid position of the subtalar joints and zero or at most 5—15 degrees plantar flexion of the talocrural joint

The fracture pattern seen in these cases was composed of a main shear ing fracture through the posterior articular facet running in to the sinus tarsi, which was fragmented and a longitudinal fracture in the lateral

Table 1 Factors involved in the production of experimental os calcis fractures

No	Age	Achilles-tension (Kp)	Position of the foot in degrees				Maximum force (Kp)	Fracture group	Type of fracture	Authors classification
			dorsiflexion	plantar flexion	supination	pronation				
1	74	20	—	10	10	—	—	VII	2	IV
2	57	20	—	10	—	—	—	VI	2	II
3	83	30	10	—	—	5	—	VI	1	III
4	74	40	10	—	—	5	—	VI	1	III
5	59	10	—	10	15	—	—	VII	2	IV
6	25	30	—	10	15	—	—	VII	2	IV
7	84	10	10	—	—	10	—	V		I
8	72	40	—	10	5	—	—	VI	2	II
9	60	10	—	10	10	—	—	VII	2	IV
10	58	30	—	10	15	—	—	VII	2	IV
11	38	10	—	15	15	—	—	VII	2	IV
12	50	20	10	—	—	5	—	VI	1	III
13	34	10	—	10	10	—	—	VII	2	IV
14	55	10	—	10	—	—	—	VI	2	II
15	77	30	—	10	15	—	—	VII	2	IV
16	89	10	10	—	—	5	—	VI	1	III
17	70	30	5	—	—	10	—	V		I
18	63	20	5	—	—	5	—	VI	1	III
19	64	—	10	—	—	—	—	VI	1	III
20	73	10	5	—	—	10	—	V		I
21	65	30	—	10	10	—	1040	VII	2	IV
22	73	10	—	10	—	—	1160	VI	2	II
23	84	20	10	—	—	—	850	VI	1	III
24	84	10	—	10	—	—	885	VII	2	IV
25	82	—	—	—	—	—	695	VII	1	III
26	82	10	—	10	—	—	885	VII	2	IV
27	80	20	5	—	—	10	855	V		I
28	75	20	5	—	—	—	880	VI	2	III
29	76	—	—	—	—	—	1110	VI	2	II
30	76	—	—	10	10	—	840	VII	2	IV
31	57	20	5	—	—	—	1075	VI	1	III
32	62	30	5	—	—	5	1125	VI	1	III
Experiments with high speed camera at the moment of impact										
33	73	—	5	—	—	—	700	VII	2	III
34	75	—	5	—	—	—	600	VI	2	III
35	79	—	—	5	5	—	825	VII	2	IV
36	78	—	—	—	—	—	865	VII	2	IV

wall of the os calcis Usually, in this type of fracture the os calcis is separated into a antero medial fragment carrying part of the posterior facet and a postero lateral fragment carrying the lateral part of this facet This latter part very often is compressed and tilted in relation to the main antero medial fragment producing a dislocation within the posterior articular facet This type of fracture corresponds clinically to Group VI or VII according to Widen s classification and to type 2 according to Palmer s classification

Type III (fig 9)

Fractures of type III occurred when the foot was in midposition with regards to the subtalar joint while there was 5—10 degrees of dorsiflexion in the talocrural joint

The fracture pattern seen in these cases was again composed of the shearing fracture through the posterior articular facet into the sinus tarsi which was fragmented The lateral wall on the larger postero-lateral fragment is fractured at the level of the posterior facet This latter fracture runs behind the posterior facet which becomes depressed in relation to the remainder of the large postero lateral fragment

This type of fracture corresponds clinically to group VI or VII according to Widen s classification and to type 1 acording to Palmer s classification

Type IV (fig 10)

Fractures of type IV occurred when the foot was supinated at least 10 degrees and plantar flexed 5—15 degrees through the talocrural joint

In these cases the shearing fracture runs close to the medial border of the posterior articular facet into the sinus tarsi which is fragmented There also exists in this type a fracture running from the sinus tarsi along the lateral wall of the tuber

The main postero-lateral fragment carrying the entire posterior articular facet, is compressed thus creating a diastasis between the talus and the facet

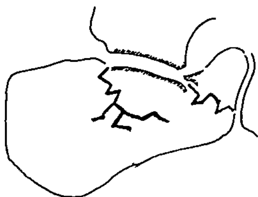
This type of fracture corresponds clinically to group VII according to Widen s classification and to Palmer s type 2

Table 1 Factors involved in the production of experimental os calcis fractures

No	Age	[illegible] (Kp)	Position of the foot in degrees: dorsal flexion	plantar flexion	supination	pronation	Maximum force (Kp)	Fracture group	Type of fracture	Authors classification
1	7[illegible]	20	—	10	10	—	—	VII	2	IV
2	57	[illegible]0	—	10	—	—	—	VI	2	II
[illegible]	83	[illegible]	10	—	—	5	—	VI	1	III
[illegible]	74	40	10	—	—	5	—	VI	1	III
[illegible]	[illegible]9	[illegible]0	—	10	15	—	—	VII	2	IV
6	[illegible]	3[illegible]	—	10	15	—	—	VII	2	IV
7	[illegible]	10	10	—	—	10	—	V		I
8	72	[illegible]	—	10	5	—	—	VI	2	II
	[illegible]	10		10	10	—	—	VII	2	IV
10	[illegible]	[illegible]		10	15	—	—	VII	2	IV
11		[illegible]			15	—	—	VII	2	IV
[illegible]2		[illegible]	[illegible]	—	—	5	—	VI	1	III
1[illegible]		[illegible]		[illegible]	10	—	—	VII	2	IV
[illegible]			—	[illegible]	—	—	—	VI	2	II
1[illegible]	[illegible]	[illegible]		[illegible]	15	—	—	VII	2	IV
[illegible]	[illegible]	[illegible]	[illegible]		—	5	—	VI	1	III
[illegible]7	[illegible]	3[illegible]	[illegible]		—	10	—	V		I
1[illegible]	[illegible]	[illegible]			—	5	—	VI	1	III
	[illegible]	—		—	—	—	—	VI	1	III
[illegible]	7[illegible]	[illegible]	[illegible]		—	10	—	V		I
[illegible]1	[illegible]	[illegible]0	—		10	—	1040	VII	2	IV
[illegible]	[illegible]			[illegible]	—	—	1160	VI	2	II
[illegible]3	[illegible]	[illegible]	[illegible]	[illegible]	—	—	850	VI	1	III
	[illegible]	[illegible]	—	[illegible]	—	—	885	VII	2	IV
[illegible]	[illegible]	—	—	—	—	—	695	VII	1	III
26	[illegible]	[illegible]		0	—	—	885	VII	2	IV
[illegible]7	[illegible]0	[illegible]0	[illegible]	—	—	10	855	V		I
28	75	[illegible]	5	—	—	—	880	VI	2	III
29	76	—	—	—	—	—	1110	VI	2	II
[illegible]	76	—	—	10	10	—	840	VII	2	IV
[illegible]1	57	20	5	—	—	—	1075	VI	1	III
[illegible]2	62	[illegible]0	5	—	—	5	1125	VI	1	III
Experiments with high speed camera at the moment of impact										
[illegible]	73	—	5	—	—	—	700	VII	2	III
[illegible]4	75	—	5	—	—	—	600	VI	2	III
35	[illegible]9	—	—	5	5	—	825	VII	2	IV
36	78	—	—	—	—	—	865	VII	2	IV



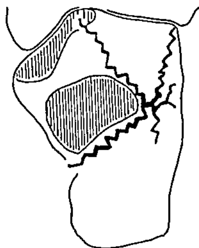
c



c



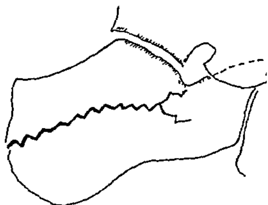
d



d



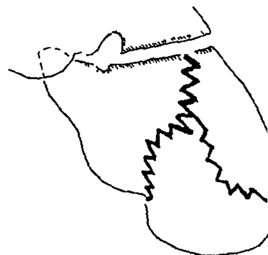
a



a



b

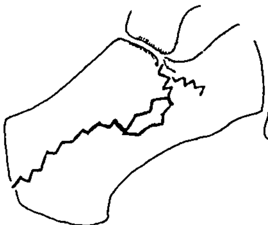


b

Fig 8 Fracture of type II (case no 14) a) lateral view b) projection I c) tomogram d) dissected specimen seen from above



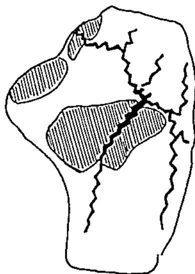
c



c



d



d



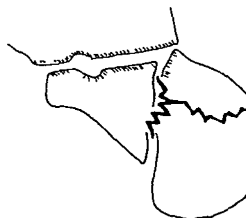
a



a



b



b

Fig 9 Fracture of type III (case no 12) a) lateral view b) projection I c) tomogram d) dissected specimen seen from above



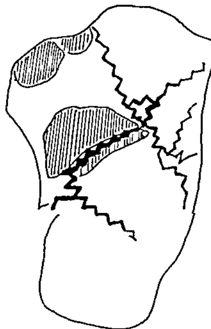
c



c



d



d



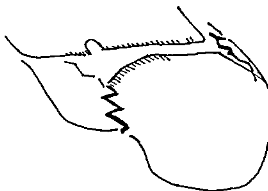
a



a



b



b

Fig 10 Fracture of type IV (case no 11) a) lateral view b) projection I c) tomogram d) dissected specimen seen from above



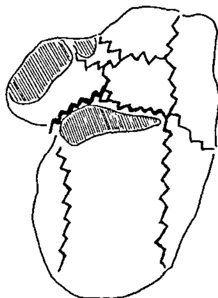
c



c



d



d

Attempts at explanation of the fracture mechanism

When a force acts on the os calcis this bone will be compressed against the talus Dependent on the direction of the force, i e the position of the foot at the moment of impact different parts of the posterior articular facet in the talo calcaneal area will sustain the trauma If the force is of sufficient magnitude it will fracture the os calcis

At the moment of impact the os calcis is forced against the talus If the force is great enough it will produce a fracture which tends to separate the os calcis in two parts one antero medial including the sustentaculum tali and one postero lateral including the tuber Thus the os calcis nearly always is separated into two halves This main fracture has been called the shearing fracture The direction of this fracture appears to be dependent on the position of the foot at the moment of impact If the foot is supinated the shearing fracture tends to run more medial (see figure 11) In these cases the resistance against the talus will then come from the greater postero-lateral fragment carrying the main part of the posterior articular facet If the remaining force is of sufficient magnitude a compression fracture of the postero lateral fragment will eventually occur if the lateral wall of this fragment also is fractured (figure 10)

If the foot is held in pronation the force will act with maximum force lateraly in the subtalar joint and the shearing fracture thus will run more lateral as seen in figure 11 In these cases (figure 7) no further compression will occur as the talus usually will act on the facet carrying

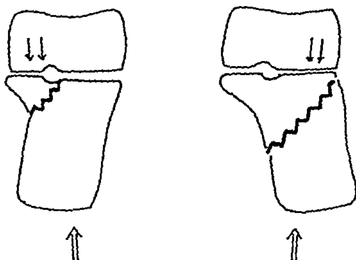


Fig 11 Posterior views of the right foot showing the direction of the shearing fractures of the os calcis in supination (A) and pronation (B)

antero-medial fragment which can slide downwards without meeting any greater resistance

Between these two borderlines the shearing fracture seems to run somewhere through the posterior articular facet Again in these cases a com pression will occur of the facet carrying the postero-lateral fragment in the same manner as just mentioned i e there must also be a fracture of the lateral wall of the os calcis (figure 8 and 9) The main antero medial fragment together with the sustentaculum tali and medial part of the separated posterior articular facet can slide downwards against practically no resistance

In all the experiments the sinus tarsi was fragmented The fragmentation of this part can be due to several factors and the shape of the talus is one of them

The tilting of the articular facet however probably depends on the fact that the ligaments in the sinus tarsi are strong and always, without exception were found uninjured at the dissections These ligaments keep the small fragments together and in their aproximate relations to the talus The articular facet on the other hand lacking such ligamentous support can be tilted downwards to obtain a more vertical direction One other possibility is of course that there is a rebound mechanism by which the smaller fragments are first depressed to the same degree as the talus at the moment of rebound they again move upwards still being attached to the talus

CLINICAL SECTION

CHAPTER 3

Survey of the Material

Since the early nineteen fifties early active exercise has along with other forms of treatment, been included in the management of fractures of the calcaneus at the Surgical Department of Akademiska Sjukhuset in Uppsala Thus during the period from January 1952 until July 1956 16 out of 26 patients with fracture of the calcaneus received early exercise therapy The results of this form of treatment during that period were favourable In many cases the functional end results were satisfactory, as the author himself has been able to confirm in a follow up examination of these patients This series however in addition to being too small had the disadvantage of being selected which disqualified it for a critical follow up study In order that the efficacy of the method might be tested on completely unselected material it was decided that from the middle of 1956 all patients with fractures of the calcaneus coming under the care of the Department unless contraindicated by special features were to be uniformly treated with active exercises started at an early stage The intention was to provide us with an unselected uniformly treated series as a basis for subsequent clinical evaluation Fairly soon it became evident however, that we could not expect to collect a sufficiently large series within a reasonable period of time In the face of this it proved necessary to turn to other sources to secure more material for the planned study From earlier investigations the Surgical Department at Akademiska Sjukhuset had positive experience in the cooperation of surgical departments in other parts of Sweden

There were two conditions which we felt were essential in making a study of this kind feasible

1 The method of treatment should not present any problems and permit a standard procedure to be followed

2 In conducting the study, one must be able to rely upon the intimate cooperation and active interest of the surgeons from other departments who have undertaken to assist in the investigation

Both these requirements were satisfied in the present investigation

Table 2 presents the hospitals which cooperated in this investigation and illustrates the distribution of cases placed at the author's disposal in

Table 2 Geographic distribution of total series

Center and date	Number of patients	Number of fractures	Number of patients treated by operation or plaster fixation
Uppsala–Enkoping Oct 1956–1959	32	33	3
Linkoping May 1957–1959	8	9	3
Norrkoping May 1957–1959	18	20	1
Karlstad June 1957–Jan 1960	8	9	1
Karlskoga May 1957–1959	5	5	1
Falun May 1957–1959	12	14	2
Sala–Sandviken 1957–Jan 1960	11	12	2
Gavle 1957–1959	23	27	1
Soderhamn–Ljusdal 1959–Jan 1960	5	5	—
Östersund 1959	9	10	1
Luleå 1957–1959	12	12	—
	143	156	15*)

*) This number includes the 6 cases of bilateral fracture in which one side was treated by operation or plaster fixation

each instance with respect to the number of fractures that were treated and the time of their treatment Originally three more surgical departments from other parts of Sweden contributed material, but these cases were excluded as they were found to have been subject to selection For various reasons, the collection of material from the different departments was begun at different times, but on the whole the investigation comprises the 3 year period 1957—59

The total series includes 143 patients with 156 fractures of the calcaneus which means that bilateral fractures occured in 13 cases

The table further shows that 15 patients have been treated by other methods In 6 cases this was occasioned by complications or other injuries situated close to the fracture site which made active exercise impossible Three cases were mistakenly treated by other methods In 6 cases of bilateral fractures, eventually one side was treated by plaster fixation or operation for reasons which will be further discussed in chapter 7 (p 64)

CHAPTER 4

Radiographic Examination

Ordinary lateral and semi axial roentgenograms usually do not reveal in detail the extent of injury in the fractured os calcis

From roentgenologic studies of clinical and experimental fractures of the calcaneus the author has formed the impression that roentgenograms taken with Broden s projection I and II provide the most valuable information for clinical evaluation of the fracture The method is based on the fact that the posterior articular facet constitutes the surface of a cone whose axis forms an angle of about 30 degrees with the long axis of the foot

The technique according to Broden (1949) is as follows

Projection I The patient supine Leg and foot are turned 45 degrees inwards with right angle flexion at the ankle joint The central ray is directed against a point 2—3 cm caudoventrally to the lateral malleolus Four pictures are taken with the tube angled 40 30 20 and 10 degrees, respectively towards the head

The picture taken with the tube angled 40 degrees shows the anterior part of the talocalcaneal joint the picture with the tube angled 10 degrees reproducing the posterior part Some of the pictures (generally those with the tube angled 30 or 20 degrees) make the articulation between the sustentaculum and the talus visible

Projection II The patient supine Leg and foot are turned 45 degrees outwards with right angle flexion at the ankle joint The central ray is directed against a point 2 cm caudoanteriorly to the medial malleolus with the tube angled about 15 degrees towards the head It is suitable to take 3 pictures with a difference of 3—4 degrees One of these will as a rule be perfect

Tomography as an aid in analysis of os calcis fractures has earlier been used by Peter R *et al* (1961) and Grewald I *et al* (1961)

Initially in the investigation a number of fractures were studied with tomography but the value of such evidence appeared insufficient to justify the amount of work examination by this technique would require In addition it would have been impossible to ensure a uniform roentgen examination of the entire series if tomography had been selected as a standard procedure since many of the hospitals which contributed to the material did not have tomographic equipment at their disposal

All patients included in the series which has been presented were subjected to roentgen examination on the first day of admission to hospital or within a few days of injury and on one or two subsequent occasions

during the convalescent period In connection with our follow-up study, all but two of the patients (cases no 55 and no 56) were again subjected to roentgen examination The examination included in all cases one lateral view, one semiaxial view and roentgenograms taken with Broden's special projections In every unilateral case a lateral roentgenogram was taken also of the normal foot

The tuber-joint angle

The so-called tuber-joint angle introduced by Bohler, has been defined as the complement of an angle formed by two lines, one of which is drawn between the upper margin of the anterior process and the upper margin of the lateral portion of the posterior articular facet, the other is drawn along the upper margin of the tuberosity (see fig 12 a and b) According to



a



b

Fig 12 Case no 76 Demonstrating the tuber joint angle on fractured (a) left foot and normal (b) right foot

Bohler the normal value of this complementary angle varies between 20 and 40 degrees In intra articular fractures of the calcaneus it is often decreased and in some cases it may be entirely obliterated or present a negative value

In the present series the tuber joint angle was measured in every roentgen examination The measurements were accurate within one degree

In order to estimate a possible effect on the observed values arising from the technique of examination the following analysis was made

Five different examiners took one roentgenogram each of the injured and uninjured foot in four patients Following this the tuber joint angle was measured The outcome of this analysis designed to assess the error of the method was that the variation in the values measured in the same foot never exceeded 3 degrees The standard deviation for the values measured in the same foot was for the four patients

In the fractured foot 1 02 0 71 0 97 and 0 71 degrees respectively

In the opposite foot 0 87 1.22 0 81 and 1.30 degrees respectively

On the whole we find that the error of the method, if evaluation is based on a single judgment amounts to 0 95 degrees and therefore is of little consequence in comparison with the individual variations in the tuber joint angle

The tuber joint angle provides a numerical expression of the degree of deformation of the calcaneus With respect to this numerical value how ever we must take into account that its individual variations normally range between 20 and 40 degrees according to Bohler The diminution of the tuber joint angle in comparison with the uninjured side must there fore be regarded as a more exact indication of the degree of compression of the fractured calcaneus In all cases included in the present series roentgenograms of the uninjured foot were on some occasion made in conjunc tion with roentgen examination of the fractured foot The diminution of the tuber joint angle could thus be defined Since no exact information is available to determine what the normal variations of the tuber joint angle are and whether the values for the right and left foot in the same indi vidual normally show appreciable individual variations a random selected series of 25 healthy individuals was obtained

In each case both feet were examined by one and the same examination The highest observed value for the tuber joint angle was 45 degrees the lowest 20 degrees No appreciable difference existed between the left and right foot (mean difference 32 5—32 3 degrees standard deviation 1 6 and maximum variat on between right and left foot was 3 degrees)

Displacement of the posterior articular surface

From anatomical studies of experimental fractures of the calcaneus (see chapter 2) and roentgenologic study of the clinical material the author has found displacement of the posterior articular facet resulting from the fracture which runs diagonally through the posterior articular surface, to be one of the most characteristic features of intra articular frac

tures of the calcaneus This displacement is best evaluated on the basis of roentgenograms taken with Broden's projections The majority of cases in the present series were examined by this technique at the time of injury and the entire series again at follow up It was found that any initial displacement of the posterior articular surface on the whole persisted, and that physical therapy had failed to have much effect upon the degree of displacement The follow-up roentgenograms show a certain filling in and rounding out of the fracture edges

Evaluation of the degree of displacement of the posterior articular surface on the basis of roentgenograms is somewhat uncertain since it is influenced by subjective criteria In an attempt to eliminate this subjective element, the series has been evaluated not only by the author, but by four other judges quite familiar with the problems involved As it was impossible to express the degree of displacement in a numerical value, the series was based on the roentgenograms, exemplified in fig 13 and 14 These were divided into two groups characterized by moderate displacement (+) or considerable displacement (+ +) respectively

With typical examples of moderate and considerable displacement as their criteria the four other judges performed an independent grading of the material The series at their disposal comprised of 88 cases of unilateral intra-articular fractures of the calcaneus The results of this evaluation are set down in table 3



Fig 13 Case no 76 Demonstrating moderat displacement (+) of the posterior articular facet



Fig 14 Case no 57 Demonstrating considerable displacement (++) of the posterior articular facet

The table shows that a unanimous judgment was reached in 65 out of the 75 cases with displacement As for the 10 cases in which opinions differed it can be noted that one case which the author assigned to be in the group with moderate displacement according to the majority verdict belonged in the group with considerable displacement We may conclude that the evaluation is reliable provided it is carried out by some one familiar with the problems involved

Table 3 Evaluation of the degree of displacement of the posterior articular surface

Author's evaluation	Majority evaluation (author and 4 other judges)			Unanimous evaluation
	0	+	++	
0	13	–	–	13
+	–	39	–	34
++	–	1	35	31

0=no displacement
+=moderate displacement
++=considerable displacement

CHAPTER 5

Statistical Methods

The following formulae have been employed in the statistical calculations

Notation Number of patients = n

Mean $\bar{x} = \frac{\sum x_i}{n}$

where x_i denotes the ith patient

Standard deviation

$$S\,D = \sqrt{\frac{\sum (x_i - \bar{x})}{n-1}}$$

Standard error of the main

$$\text{Mean} = \frac{S\,D}{\sqrt{n}}$$

and in comparisons between two groups x and y

$$\sigma_{\bar{x}-\bar{y}} = \sqrt{\frac{\sum (x_i - \bar{x})}{(n_x - 1)\, n_x} + \frac{\sum (y_i - \bar{y})^2}{(n_y - 1)\, n_y}}$$

Standard weighted percentages $\sum W_j P_j$

where P_j is the percentage in the jth subgroup,

W_j is the weight of the jth subgroup and $\sum W_j = 1$

Weighted percentages are applied when comparing groups differing in the distributions The weights W_j, are chosen to correspond approximately to the number of patients in the respective sub groups

Confidence intervals

Confidence intervals corresponding approximately to the 95 % level are given in some tables as

$$\bar{x} - \bar{y}\ \sigma \pm 2\,\bar{x} - \bar{y}$$

Significance levels

The significance analyses are given in conjunction with the tables As a rule however only significant results are presented The term significant is used in accordance with the following convention If an observed difference between two percentages (or two means) is of such a magnitude that the probability P of obtaining a difference at least as great as the observed value is greater than 0 05 (where the null hypothesis is assumed to hold), then that observed difference is said to be non significant

If $0.01 < P \leq 0.05$ the difference is said to be (probably) significant and is marked

If $0.001 < P \leq 0.01$ the difference is said to be significant and is marked *

If $0.001 \geq P$, the difference is said to be (highly) significant and is marked* *

Significance tests

The following significance tests were used

1 In percentage differences χ^2 test usually with one degree of freedom

2 In mean differences the t test if $n < 20$ but usually normally distributed

$$C.\,R = \frac{\bar{x} - \bar{y}}{\sigma_{\bar{x} - \bar{y}}}$$

3 In differences between standard weighted percentages

$$\sum W_j (P_{xj} - P_{yj})$$

a normally distributed critical ratio is produced

$$C.\,R = \frac{\sum W_j (P_{xj} - P_{yj})}{\sqrt{\sum W_j \frac{n_{xj} P_{xj} + n_{yj} P_{yj}}{n_{xj} + n_{yj}} \left(100 - \frac{n_{xj} P_{xj} + n_{yj} P_{yj}}{n_{xj} + n_{yj}}\right) \left(\frac{1}{n_{xj}} + \frac{1}{n_{yj}}\right)}}$$

where n_{xj} and n_{yj} correspond to the number of patients in the compared sub groups

CHAPTER 6

The Follow-up Series

The follow-up investigation took place during the latter part of 1960 and the early part of 1961 Of the patients included in table 2 those who had been subjected to plaster fixation or operation were excluded from the follow-up with the exception of the 6 cases of bilateral fracture in which one side was treated with early exercise Thus 134 patients remained Out of this number 5 had died Of the remaining 129 patients 121 or 93 8 % were available for clinical examination Since 11 of the patients in the follow-up series had bilateral fractures the total number of followed-up fractures was 132

Classification

Almost every author who has ever written about fractures of the calcaneus has his own views on classification of the material The author has chosen to adopt Widen s classification, mainly for the purpose of providing a basis for comparison of the present series treated with early exercise with a series subjected to a standard form of operative treatment

Table 4 Classification (according to Widen) of fractures included in total series

Classification according to Widen	Number of fractures included in follow up	Number of fractures not included in follow-up	Total
A Groups I–IV	22	8	30
B Group V	15	1	16
Group VI	59 (Palmer's Type 1 39, Type 2 20)	4	63
Group VII	36 (Palmer s Type 1 16, Type 2 20)	11	47
Total	132	24	156

The classification of the present series is illustrated by table 4 In order to present an over all picture of the material the series was broken down into the followed up and non followed up fractures

Since earlier studies in a majority of cases have demonstrated that extra-articular fractures of the calcaneus seldom give rise to persisting disability these fractures have been collected within one group A, corresponding to Widen s fracture groups I—IV Of the 22 fractures in this part of the series which were included in the follow up the majority were referable to group II i e fracture of the medial tubercle

The other main division comprise fractures through the body of the calcaneus This group B has in Widen s classification been divided into 3 subgroups

Group V The shearing fracture runs behind and below the posterior articular facet or upwards towards the posterior facet without causing any displacement of the posterior articular surface

Group VI The shearing fracture runs into the lateral portion of the posterior articular facet and causes depression of the lateral fragment

Group VII The shearing fracture runs a more medial course and causes depression of the whole or major portion of the posterior articular facet

As shown in table 4 followed up fractures belonging to groups VI and VII have been subdivided into Palmer s type 1 and type 2 Palmer (1948) subdivided the secondary compression fractures into two main types

1 The articular fragment more or less deeply impacted into the sub jacent bone, was 1—1 5 cm in height and equal to the articular surface in length
2 The articular fragment extended posteriorly to include the upper part of the tuber whereby the tuber was split in two portions which gaped apart posteriorly

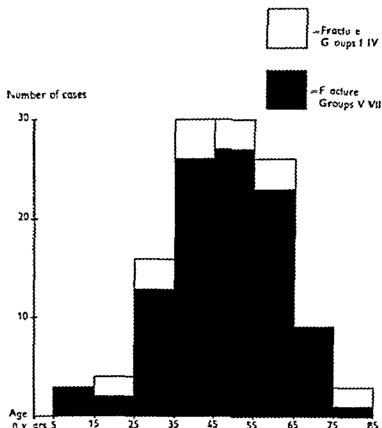
Fractures assigned to groups V—VII are in the present study designated as intra articular fractures

Of the 110 unilateral fracture included in the follow up 61 involved the right and 49 the left side

Age and sex distribution

The age distribution of the follow up series is illustrated by diagram 1 The bulk of the material is concentrated within the age groups between 30 and 60 Seen as a whole the age distribution shows good general agreement with the figures presented by other authors (Widen Ahlberg Gollach, Arnesen) The average age of the entire follow up series is 47 3 years

Diagram 1   Distribution of follow up series with respect to age and fracture groups



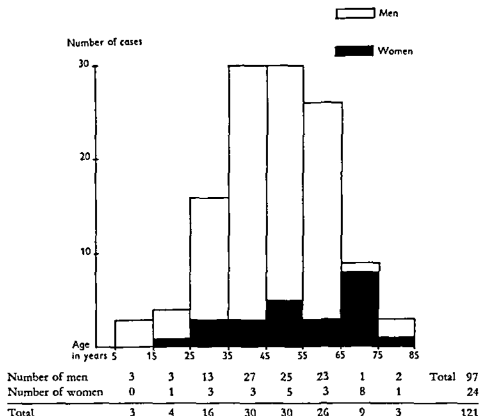
Number of cases									
Groups I—IV	0	2	3	4	3	3	0	2	Total 17
Groups V—VII	3	2	13	26	27	23	9	1	104
Total	3	4	16	30	30	26	9	3	„ 121

(cases with bilateral fractures referable to two different groups have been assigned to the higher group)

The distribution of the sexes is illustrated in diagram 2 Twenty-four or 19 8 % of the patients are women This percentage is about the same as in Widen s series but somewhat higher than the figures reported by other authors (Ahlberg 14 1 % Gollach 9 %) The average age for women is somewhat higher than for men (54 4 as against 45 9 years)

From these two diagrams it is further evident that the milder and the more severe forms of fracture are fairly evenly distributed over the different age groups By contrast we find that the majority of women are referable to the higher age groups

Diagram 2 Sex and age distribution of follow up series



Number of men	3	3	13	27	25	23	1	2	Total 97
Number of women	0	1	3	3	5	3	8	1	24
Total	3	4	16	30	30	26	9	3	121

Mode of injury

Most of the calcaneal fractures in this series were caused by falls from a height The mode of injury varies however with respect to fracture group Almost half of the patients assigned to fracture groups I—IV representing the milder forms of fracture, incurred their injuries in traffic accidents or had their foot crushed In one case the fracture was due to an accident with explosives

The more severe forms of fracture assigned to groups V—VII, are almost without exception the result of a fall from heights varying from 0 5 to 8 metres A rough estimation of the average falling height for men and women shows that there is a difference for men, the average heights is 3 4 metres for women 1 3 metres The highest average falling height 4 3 metres is found for the 6 cases of bilateral, intra articular fracture

Concomitant injuries

Twenty-nine of the patients in the follow-up series had incurred other substantial injuries simultaneously with the calcaneal fracture This amounts to 23 9 %, approximately the same incidence as reported by Ahlberg and Arnesen Both Widen and Olofsson (1940) on the other hand, report a considerably lower incidence of concomitant injuries (8 3 and 8 7 % respectively)

The following injuries were noted

Vertebral fracture (single or multiple)	5 cases
Pelvic fracture	4
Fracture of the femoral neck	2
Femoral fracture	1
Fracture of the condyle of the knee	3
Lower leg fracture	1
Malleolar fracture	3
Metatarsal fracture	2
Fracture of the radius	8 (including one case of bilateral fracture)
Fracture of the wrist	2 cases
Costal fracture	1

Treatment

The great majority of patients (112 out of 121 that were followed up), were hospitalized for some time following injury Treatment was based on the following principles

1 Bed rest with the injured foot elevated
2 Active exercises initiated on the first or second day following injury, under the supervision of a physical therapist The exercises were designed to aid articular mobility in the entire foot

Swelling of the soft tissues around the fracture site and the pain normally experienced during the first few days following injury required caution in the beginning after about one week the range of mobility could be gradually increased and patients were instructed in active exercises designed to improve the total range of mobility with the emphasis on pronation and supination After their discharge from hospital the patients were allowed to be up and walk on crutches without weight bearing The patient continued with active exercises often supervised by a physical therapist Weight bearing was permitted by individual standards but as a rule after 7—9

weeks A little over half of the patients used an arch support type for some time after weight bearing was allowed

The treatment of outpatients was on the whole carried out along similiar lines

Length of hospitalization

The majority of patients with extra articular fractures were hospitalized even though there was no actual indication for hospital treatment

The average length of hospitalization for patients with intra articular fractures is illustrated by the table below

We find that the average length of hospitalization for cases with uni lateral intra articular fractures not associated with other substantial injuries is 15 8 days — a little more than 2 weeks This may seem a high figure but the length of hospitalization is largely due to the fact that the patients in this series were intentionally kept in hospital as long as possible in order to guarantee uninterrupted exercise therapy in particular during the immediate post injury period

For the 12 cases with unilateral fractures of the calcaneus associated with other injuries tending to prolong hospitalization the average hospita lization time is naturally, considerably longer (43 8 days) For the 11 cases of bilateral fracture the average length of hospitalization is 38 5 days

Table 5 Average hospita lization time for patients with intra articular frac tures

	Number of cases	Average hos pitalization time in days (range)
A Unilateral fractures		
1 Without other substan tial injuries	77	15 8 (2–53)
2 With concomitant inju r es prolonging hospi talization	12	43 8 (14–95)
3 Outpatient care	4	0
B Bilateral fractures	11	38 5 (7–10[illegible])

Follow up procedure

All patients included in the follow up series were examined [illegible] author in person About one third of those in the series were [illegible] repeated examinations For this follow up examination th[illegible]

as a rule requested to come to the hospital where they had been treated Here a subjective history was taken and the patient subjected to clinical and roentgenographic examination In a few isolated cases the follow up examination took place in the patient's home or at his place of work, in which case roentgen examinations were taken at a later date at the nearest hospital The subjective history was intended to determine the presence of pain at rest and following use and the type of function producing pain The history further included any information about swelling around the injured ankle following use stiffness, and the patient's subjective evaluation of walking function on both flat and rough surfaces Finally the patient was required to evaluate his occupational fitness

For the purpose of the follow-up analysis, the subjective evaluation of function were graded according to a system which is essentially identical with that of Widén The following four gradations were used

1 *Excellent* No subjective symptoms and unimpaired occupational fitness following recovery

2 *Good* Negligible subjective symptoms causing no impairment of occupational fitness The symptoms which were tolerated for classification of the results as "good" were very slight and took the form of "weather sensitivity" or an occasional twitch in the lateral aspect of the foot following maximum exertion

3 *Fair* Moderate subjective symptoms consisting of pain following exertion Many of the patients assigned to this group reported transient stiffness of the injured foot in the morning and swelling of the ankle following use These patients have returned to their former employment, but in most cases the symptoms required a certain restriction of activity at work They did consequently not regain full occupational fitness

4 *Poor* Pronounced symptoms Pain following even slight use with difficulty in walking on rough surfaces Stiffness of the joint and swelling around the joint after moderate use As a rule there is a loss of occupational fitness and many of these patients have been forced to turn to less strenuous work

"Excellent" and "good" results were designated as *favourable* with respect to function "fair" and "poor" results as functionally unfavourable

This grading is naturally influenced by the author's subjective views, but on the whole one may say that the essential difference between unfavourable and favourable functional results lies in the total absence of any restriction of occupational fitness in the latter group

The clinical examination included inspection of the injured foot and comparison with the opposite side In addition the patient's gait and his ability to walk on his toes and heel were evaluated Any valgus or varus

deformity was recorded and as well as any broadening of the heel region Pain on pressure and any sensory or circulatory impairment in the injured foot was also noted as well as hammer toe deformity and callous formation The girth of the calves was measured at the greatest part and measurements were made to determine the mobility of the subtalar and talocrural joints

On the basis of the roentgenograms taken at the time of injury and at follow up the tuber joint angle was measured and compared with the value for the opposite foot The roentgenograms further served to identify remaining displacement and deformation of the subtalar articular surface and to detect any signs of degenerative arthrosis

The fractures of primary clinical interest are those involving the joint, which in this series have been assigned to group V—VII The follow up results which are subsequently presented are primarily based on this type of fracture Table 6 shows the distribution of the entire follow up series with respect to fracture groups and functional results

In order to create a homogeneous group of unilateral intra articular fractures the following cases were excluded from the series

1 All 17 cases assigned to groups I—IV

2 Unilateral fractures assigned to groups V—VII with severe concomitant injuries which had an unfavourable effect on the end results In this series there were 8 such cases

3 Bilateral fractures in which both were classified in any of the groups V—VII

By these eliminations we obtain a series consisting exclusively of unilateral intra articular fractures and comprising 90 cases in all

This series has been designated the Comparative series

Table 6 Distribution of follow up series with respect to fracture groups and functional results

Functional results	Fracture groups I—IV	Fracture group V	Unilateral fractures Fracture groups VI—VII: Without concomitant injuries causing functional impairment	Unilateral fractures Fracture groups VI—VII: With concomitant injuries causing functional impairment	Bilateral intra articular fractures	Total
Excellent	15	12	20	1		48
Good	2	1	25	3		31
Fair			18	2	2	22
Poor			14	2	4	20
Total	17	13	77	8	6	121

We find from table 6 that 79 patients in the entire follow-up series present favourable functional results, which amounts to 65.3 %. If we consider only the patients within the comparative series, the corresponding figures are 58 and 64.4 % respectively.

Length of follow-up

Experience from several major follow-up studies of calcaneal fractures indicates that the interval between injury and follow-up should not be less than 2 years. Some authors (Essex Lopresti, Lindsay & Dewar) maintain, on the other hand, that a follow up period of 1½ years is sufficient and that no subjective deterioration of the patient's condition appears to take place after that time.

In the present series the length of the follow up period varies from 1 to 4½ years. For 81.5 % of the series the time of follow-up is 1½ years or more. Of the 22 patients for whom the length of follow up has varied between 1 and 1½ years, all but three had returned to work at least 6 months prior to follow up. The prolonged occupational disability in those 3 cases was largely due to other factors. In the majority of cases, therefore, function of the injured foot had been tested under normal conditions for at least 6 months before the follow up took place.

Since the interval between injury and follow-up varies between such a wide range (1—4½ years) and for part of the series has been relatively short, it will be of interest to compare the length of the observation period in relation to the different functional results. Table 7 illustrates the distribution of the series in this respect.

We find from this table that the period of follow up varies from 12 to 53 months. We cannot detect any tendency for the results to vary with follow up periods of different length.

Table 7. Length of observation period (and range) in months within different groups. Comparative series

Functional results	Length of observation period average time in months (and range)				Number of cases		Total
	Fracture group V		Fracture groups VI—VII		Fracture groups V	VI—VII	
Excellent	28.5	(15—46)	29.3	(12—49)	12	20	32
Good	42.0		26.3	(12—53)	1	25	26
Fair			25.4	(12—39)		18	18
Poor			29.6	(14—49)		14	14
Total	29.5	(15—46)	27.5	(12—53)	13	77	90

CHAPTER 7

Follow-Up Results

A Extra articular fractures of the calcaneus

The follow up series includes 17 cases of unilateral fracture assigned to groups I—IV 11 of them referable to group II which comprises fractures of the medial tubercle The functional results in these cases were invariably favourable and none of the 4 patients insured under the Workmens Compensation Act were found to have any persisting disability The period of occupational disability had been relatively short Fifteen of the patients returned to full employment within 3 months of injury the remaining two patients within 4 months On the basis of the objective findings all patients were rated as fully recovered These results are entirely consistent with those reported by other authors regardless of the method of treatment (Essex Lopresti Widen and others)

B Unilateral intra articular fractures of the calcaneus

The follow up results presented in this section refer to the cases comprising the Comparative Series i e unilateral fractures assigned to fracture groups V—VII The criteria by which this comparative series was selected from the total follow-up series are evident from table 6 on page 45 This selection procedure provided a fairly large and well defined series of intra articular fractures, permitting comparison of the objective findings in each individual case with the normal state as evidenced by the uninjured foot

Subjective symptoms

Although the follow up period in the present series is fairly short judging from the results of previous investigations the author considers it sufficient for the purpose of this study Essex Lopresti for instance states that no appreciable change in the results occurs after 1½ years Lindsay and Dewar found in a follow up series of 147 intra articular fractures of the calcaneus with an average length of follow up of 8 years

that the subjective symptoms had been stabilized between 16½ and 19½ months following injury In only 9 cases did they find that any impairment of the patients condition had taken place at a later date

We may recall at this point, that for 80 % of cases in the follow up comparatives series the length of follow up was established as 1½ years or more

The most common and apparently the most persistent symptom of which the patients complain is pain in the foot when walking on rough surfaces or following use The pain is almost invariably localized to the region around the lateral malleolus in particular the anterior aspect The severity of the symptoms is naturally dependent on the patient s activity An elderly person or a young individual with sedentary work has lesser demands on good function of the foot than someone performing strenuous activity, and may consequently experience less discomfort from the injured foot In the comparative series 60 % of the patients complained of pain in the foot brought on by strenuous activity or by walking on rough ground This percentage covers such symptoms in its entire range and consequently includes even those patients with only occasional complaints of pain In many of these cases the symptoms were slight and did not impair the patients occupational fitness, nor did they require any appreciable restriction of recreational activities In a little over 20 % of cases, the patient complained of symptoms described as ' rheumatic pain brought on by changes in the weather In a number of cases this constituted the sole subjective discomfort

Gait

At follow up the patients were examined with respect to their gait and their ability to walk on the toes A patient s gait was designated as limping if he walked with a distinct limp or showed a disturbance of gait in which the foot strikes the ground in a stiff and inelastic manner Patients who walked without an obvious limp but were unable to walk on the toes were classed as having an impaired gait

The table below shows the distribution of the comparative series with respect to gait and functional results

This table shows that 67 out of the 90 cases or 74 4 % had an entirely normal gait at the time of follow up The patients with the least favourable results in this respect, i e those who limp and are unable to walk on the toes constitute 10 % of the series

The correlation between gait and functional results is very high We find that of 67 cases with normal gait 57 are referable to the groups designated by excellent or good functional results, whereas only one of

Table 8 Distribution of cases with respect to gait and functional results

Functional results	Normal gait on flat surface and ability to walk on toes	Normal gait on flat surface but inability to walk on toes	Limping on flat surface and inability to walk on toes	Number of cases
Excellent	31	1		32
Good	26			26
Fair	10	6	2	18
Poor		7	7	14
Total	67	14	9	90

the cases with impaired gait has been classed as a good functional result The difference observed between the group with normal gait and the one with impaired gait with respect to the functional results is statistically significant (* *) It should be noted that all cases with favourable functional results present a normal gait except one

Widen observed almost identical percentages of impaired gait in his follow up study of unilateral fractures The incidence found in Gollasche s series is 20 %

Atrophy of the calf muscles

The treatment of the present series of fractures of the calcaneus by active and passive exercises initiated at an early stage was designed to prevent or minimize the development of atrophy in particular of the calf muscles as a result of immobilization

During the follow up examination the girth of the calves on both the injured and the healthy side was measured at their greatest circumference A difference of girth exceeding 1 cm was registered as atrophy Five cases had to be excluded for various reasons, including varices The distribution

Table 9 Distribution of cases with respect to muscular atrophy and functional results

Functional results	Decrease in girth of the calf in relation to normal side		Number of cases
	None or not exceeding 1 cm	Exceeding 1 cm	
Excellent	31	1	32
Good	21	3	24
Fair	11	5	16
Poor	6	7	13
Total	69	16	85

of the remaining cases with respect to the presence or absence of muscular atrophy and the functional results is illustrated by table 9

We find that 69 out of 85 cases (81 2 %) present no evidence of muscular atrophy at the time of follow-up

A strong correlation exists between muscular atrophy and functional results Thus we find that 75 4 % of the 69 cases without appreciable atrophy were referable to the group presenting excellent or good functional results, as against only 25 0 % of the 16 cases with evidence of atrophy This difference is statistically significant (*)

In Ahlberg s series of 111 fractures of the calcaneus subjected to various forms of treatment, no significant difference was found with respect to muscular atrophy between the cases treated with early exercises and those treated by other methods In Widen s series of cases mainly treated by operation on the other hand a significant correlation emerged between functional results and muscular atrophy

Broadening of the heel

In its acute stage intra-articular fracture of the calcaneus is always associated with considerable swelling and discoloration of the heel region, in particular its lateral aspect When this edema has subsided some increase in the breadth of the heel portion persists in most cases because of the fact that the fracture has caused some deformation of the heel bone This increase in breadth has on the whole remained constant on comparison of the roentgenograms taken at the time of injury and at follow-up It would seem, therefore, that early exercise therapy has had no effect in this respect

The breadth of the calcaneus was measured in both feet with a caliper at a point immediately below the tip of the lateral malleolus The difference in breadth between the two feet was recorded Table 10 shows the observed values in this series differentiated into one group with an increase of breadth of less than 1 cm and one group with an increase of 1 cm or more correlated with the functional results

It is to be noted that almost exactly half of the series presents an increase *of breadth of 1 cm or more*

There is a correlation between broadening of the heel and functional results The observed difference is statistically significant (**)

Widen found in his series, evaluated by identical criteria no significant difference Aars and Bie reported moderate or marked lateral thickening in somewhat over half of a series treated with traction according to Arnesen s method

Table 10 Distribution of cases with respect to broadening of the heel and functional results

Functional results	Increase in breadth		Number of cases
	< 1 cm	≥ 1 cm	
Excellent	22	10	32
Good	15	11	26
Fair	5	13	18
Poor	2	12	14
Total	44	46	90

Valgus deformity

Due to the shortening and broadening of the heel resulting from fractures of the calcaneus with serious joint involvement it is virtually im possible to rely upon roentgenographic evidence in order to determine the presence or absence of appreciable valgus deformity with a reasonable degree of certainty In the present evaluation of this factor the author has adopted the following procedure With the patient standing barefoot on a level surface the heel region in both feet was inspected from the rear Evaluation of valgus deformity was based on comparison of the injured with the uninvolved side

Table 11 shows the incidence of persiting valgus deformity and the distribution of such cases in relation to the functional results

The table shows that valgus deformity in comparison with the uninjured side is present in 21 cases, or 23 3 % of the series In 8 more cases valgus deformity was diagnosed, but this was about equal to that found in the uninvolved foot

There is a fairly strong correlation between valgus deformity and functional results Persisting valgus deformity is found in only 4 of the 58

Table 11 Distribution of cases with respect to valgus deformity and functional results

Functional results	Valgus deformity of fractured foot	No valgus deformity or deformity equal on both sides	Number of cases
Excellent	1	31	32
Good	3	23	26
Fair	4	14	18
Poor	13	1	14
Total	21	69	90

of the remaining cases with respect to the presence or absence of muscular atrophy and the functional results is illustrated by table 9

We find that 69 out of 85 cases (81,2 %) present no evidence of muscular atrophy at the time of follow up

A strong correlation exists between muscular atrophy and functional results Thus we find that 75 4 % of the 69 cases without appreciable atrophy were referable to the group presenting excellent or good functional results, as against only 25 0 % of the 16 cases with evidence of atrophy This difference is statistically significant (***)

In Ahlberg s series of 111 fractures of the calcaneus subjected to various forms of treatment, no significant difference was found with respect to muscular atrophy between the cases treated with early exercises and those treated by other methods In Widen s series of cases mainly treated by operation, on the other hand, a significant correlation emerged between functional results and muscular atrophy

Broadening of the heel

In its acute stage intra-articular fracture of the calcaneus is always associated with considerable swelling and discoloration of the heel region, in particular its lateral aspect When this edema has subsided some increase in the breadth of the heel portion persists in most cases because of the fact that the fracture has caused some deformation of the heel bone This increase in breadth has on the whole remained constant on comparison of the roentgenograms taken at the time of injury and at follow-up It would seem therefore, that early exercise therapy has had no effect in this respect

The breadth of the calcaneus was measured in both feet with a caliper at a point immediately below the tip of the lateral malleolus The difference in breadth between the two feet was recorded Table 10 shows the observed values in this series, differentiated into one group with an increase of breadth of less than 1 cm and one group with an increase of 1 cm or more, correlated with the functional results

It is to be noted that almost exactly half of the series presents an increase of breadth of 1 cm or more

There is a correlation between broadening of the heel and functional results The observed difference is statistically significant (**)

Widén found in his series, evaluated by identical criteria, no significant difference Aars and Bie reported moderate or marked lateral thickening in somewhat over half of a series treated with traction according to Arnesen s method

flexion, in that women presented a somewhat higher value for plantar flexion and the men for dorsiflexion In table 12 the series has been differentiated by sex The tables give the mean values for dorsiflexion and plantar flexion in the uninjured foot and the observed values in the fractured foot for the sexes separately

This table shows that plantar flexion following fracture of the calcaneus appears somewhat more affected in the female group

Table 13 illustrates both the mobility on dorsiflexion and on plantar flexion and the total range of movement at the talocrural joint in comparison with the uninjured side

It emerges from this table that the mobility of the talocrural joint has on the whole been fairly well maintained in comparison with the mobility on the uninjured side An increase of the mobility such as Watson Jones (1943) found in a number of cases has not been observed in a single case in this series If we consider only those cases in which the loss of mobility exceeded the error measurement of 5 degrees we find a decrease of 10 degrees or more in the total range of movement in 28 out of 90 cases or 31 1 % The table further shows that this loss of mobility is largely due to a decrease of plantar flexion

A correlation exists between mobility of the talocrural joint and the functional results This emerges from the fact that 48 out of the 62 cases with equal mobility on both sides or a loss of mobility not exceeding 5 degrees representing the error of measurement present favourable functional results (77 4 %) as against 10 out of 28 (35 7 %) cases with a loss of mobility amounting to 10 degrees or more This difference is statistically significant (***)

Table 13 Distribution of cases with respect to mobility of the talocrural joint in comparison with the uninjured side and functional results

Functional results	Mobility of the talocrural joint in comparison with uninjured side: Dorsiflexion		Plantar flexion		Total range of movement		Number of cases
	Identical or decreased by at most 5	Decreased by 10 or more	Identical or decreased by at most 5	Decreased by 10° or more	Identical or decreased by at most 5	Decreased by 10° or more	
Excellent	32		31	1	27	5	32
Good	26		25	1	21	5	26
Fair	18		14	4	11	7	18
Poor	11	3	5	9	3	11	14
Total	87	3	75	15	62	28	90

Mobility of the subtalar joint

Function of the subtalar joint is of particular interest following intra-articular fractures of the calcaneus, since the injury primarily affects the subtalar joint but often also involves the calcaneocuboid joint

In terms of anatomy, the subtalar joint consists of a posterior portion articulating between the talus and the calcaneus, and an anterior part articulating between the talus calcaneus and the cuboid bone The anterior portion also forms part of Chopart s joint The motion in these two joints occurs simultaneously about a common axis, and in terms of mechanics the joint may be regarded as a functional unit The common axis runs from the inferior posterolateral margin of the calcaneus forward, upward and medially through the neck of the talus The movement at this joint is a complex one consisting on the one hand of inversion-adduction-plantar flexion, here designated as supination and on the other of eversion-abduction dorsiflexion here designated as pronation In measuring the range of pronation and supination in the anterior part of the foot, the mobility of the subtalar joint is added to the range of motion of Chopart s joint and the tarso metarsal joints Wilson (1925) has pointed out that a partial or total loss of mobility at the subtalar joint results in a compensatory increase of the mobility of the metatarsal joints

The mobility of the subtalar joint at the time of follow up was measured as follows

The patient was placed in the prone position with the foot in the middle position between pronation and supination and between dorsiflexion and plantar flexion In this position the midline was marked by a line drawn on the calf and the heel From this position pronation and supination movements were performed and the total angle was measured to within 5 degrees Through this procedure one eliminates the component contributed by the movements at the metartarsal joints when pronation and supination of the anterior part of the foot are measured on the plantar surface

In the following sections the results of these measurements will be designated as the mobility of the subtalar joint

The total range of pronation and supination was measured in the following way

The patient was placed in the supine position with the foot in the middle position A protractor was placed on the plantar surface of the foot at the level of the metatarsal heads and the angle formed between the protractor and a plane perpendicular to the longitudinal axis of the leg was measured

On comparing the results of the two techniques used to measure pronation and supination of the foot we find that in many of the cases which show a loss of mobility on measurement with the first method mobility is also decreased when the total range of pronation and supination is measured This is illustrated by table 14

Table 14 Distribution of cases with respect to range of pronation and supination as measured in the anterior part of the foot and in the heel

Measured in the heel	Measured in the anterior part of the foot			Number of cases
	Abolished	Restricted	Normal	
Abolished	2	18	—	20
Restricted	—	28	6	34
Normal	—	—	36	36
Total	2	46	42	90

These results show that in the majority of cases, or 18 out of 20 a total loss of mobility at the subtalar joint coincides with a restriction of mobility on measurement of the total range of pronation and supination in the foot This may be interpreted as a compensatory increase in mobility at the metatarsal joints The table also illustrates that the normal mobility of the subtalar joint coincides with normal values for the total range of pronation and supination of the foot

Since fracture of the calcaneus primarily involves the subtalar joint the values resulting from measurement in the heel where chosen as a criterion of the follow up results The same procedure was followed by Widen, which facilitates comparison with his series

Table 15 shows the distribution of the series with respect to mibility at the subtalar joint and functional results

If we regard mobility at the subtalar joint as abolished if it does not exceed 5 degrees we find a total loss of mobility in 20 out of the 90 cases, amounting to 22 2 % There is a marked correlation between mobility of the subtalar joint and functional results On the 58 cases presenting favourable functional results mobility at the subtalar joint is abolished only in 4 cases In 32 cases of unfavourable results 16 showed abolition of subtalar movement The difference is statistically significant (***) It further emerges from this table that the mean mobility in the group marked by excellent functional results has been fairly well maintained in comparison with the mean value observed in the uninjured foot, in direct contrast to the values presented by the group with poor functional results

Table 15 Distribution of cases with respect to range of mobility of the subtalar joint mean mobility in comparison with the uninjured side and functional results

Functional results	Fractured foot							Uninjured foot	Number of cases
	Mobility of the subtalar joint						Mean mobility in degrees	Mean mobility in degrees	
	0 – 5°	10°	15°	20°	25°	30°			
Excellent	2	1	5	6	16	2	20.9	26.2	32
Good	2	6	7	9	1	1	15.6	24.2	26
Fair	6	5	3	3	1		10.8	25.0	18
Poor	10	2	2				5.4	25.7	14
Total	20	14	17	18	18	3	15.2	25.3	90

In view of the normal variations in the mobility of the subtalar joint the loss of mobility as compared with the uninjured foot in each individual case will provide a more exact measure of the true mobility at the subtalar joint Table 16 presents the values estimated for this loss of mobility in the present series in relation to the functional results

We find from this table that normal mobility i e equal to the mobility on the uninjured side is observed in 36 out of the 90 cases We can again discern a correlation with the functional results Of the 58 cases with favourable functional results 34, or 58 6 %, presented a mobility equal to that of the normal side The corresponding figures for the two groups representing unfavourable functional results are 2 out of 32 cases, or 6 3 % This difference is statistically significant (***)

Table 16 Distribution of cases with respect to mobility of the subtalar joint as compared to the uninjured foot and functional results

Functional results	Loss of mobility in comparison with uninjured foot						Number of cases
	0° – 5	10°	15	20°	25°	30°	
Excellent	23	6	2	1			32
Good	11	9	6				26
Fair	2	8	2	5	1		18
Poor		1	2	6	4	1	14
Total	36	24	12	12	5	1	90

Tuber-joint angle

The tuber joint angle as defined earlier (p 36) is a relative measure of the degree of compression in fractures of the calcaneus Satisfactory roentgenologic evidence of this aspect was available for 85 of the 90 cases in the comparative series For 3 further cases roentgenograms were taken at the time of injury, but no follow up pictures were available As appears in a previous section a standard roentgen procedure was followed at the various hospitals but the quality of the roentgenograms varied from place to place Nevertheless the roentgenograms permit evaluation of the features which are of interest for the purpose of this investigation The absence of plaster casts to obscure the roentgenograms has proved of particular advantage in the measurement of the tuber joint angle

Table 17 presents the distribution of the series differential into 3 subgroups according to the size of the tuber joint angle at follow up with respect to the functional results

Table 17 Distribution of cases with respect to tuber joint angle at follow up and functional results

Functional results	Tuber joint angle at follow up			Number of cases
	neg –0	1 –10	> 10	
Excellent	4	4	21	29
Good	4	6	15	25
Fair	4	5	8	17
Poor	8	2	4	14
Total	20	17	48	85

The results set down in this table show that of 48 cases with a tuber-joint angle exceeding 10 degrees 36 or 75 0 % present favourable functional results In 37 cases with a tuber joint angle of 10 degrees or less the corresponding incidence is 18 or 48 6 % The difference of 26 4 % is statistically significant (*) These figures are approximately the same as those reported by Widen from his operated series and by Aars and Bie from a series treated by traction ad modum Arnesen

The values found for the tuber joint angle at the time of follow up varied in the present series between +29 degrees and —25 degrees At the time of injury the values ranged between +32 degrees and —12 degrees The mean value for the total series is 9 3 degrees at the time of follow up as against 12 5 degrees at the time of injury This secondary compression has also been noted by other authors (Bohler Gollasch Widen)

Table 18 Distribution of cases with respect to functional results and mean tuber joint angle at time of injury and at follow up

Functional results	Mean value (and range) in degrees		Mean diminution at follow up (and range) in degrees	Number of cases
	At time of injury	At follow up		
Excellent	17 8 (7 —+32)	14 8 (11—+29)	3 0 (0—10)	29
Good	12 5 (10—+26)	10 6 (12—+26)	1 9 (0— 6)	25
Fair	10 7 (6 —+25)	7 9 (8 —+22)	2 8 (0— 8)	17
Poor	3 9 (12—+24)	1 9 (25—+22)	5 8 (1—15)	14
Total	12 5 (12—+32)	9 3 (25—+29)	3 2 (0—15)	85

From table 18 it is evident that the secondary diminution of the tuber-joint angle varies from 0 to 15 degrees The table further illustrates the incidence of such secondary compression in the groups differentiated by functional results The mean values for the different groups present fairly large variations The mean value for the group with least satisfactory function (poor results) is considerably lower than the mean value for the total series (3 2 degrees)

The normal variations of the tuber joint angle have in the present series been established as ranging from 20 to 45 degrees In view of these large normal variations the diminution of the tuber joint angle in comparison with the uninvolved side should provide a more exact measure of the degree of compression in each individual case Since roentgenograms of the uninjured side were available for the entire comparative series, it was possible to estimate this difference

Table 19 Distribution of cases with respect to functional results and diminution of tuber joint angle at follow up in comparison with the uninjured foot

Functional results	Diminution at follow up in comparison with uninjured foot					Mean diminution at follow up in de grees	Number of cases
	≤ 10	11°—20°	21 —30°	31°—40	> 40°		
Excellent	8	8	8	5		19 7	29
Good	1	11	11	1	1	21 4	25
Fair	1	8	3	4	1	24 3	17
Poor		4	2	4	4	32 6	14
Total	10	31	24	14	6	23 2	85

Table 19 presents the distribution of the series with respect both to the diminution of the tuber joint angle in comparison with the uninjured foot and to the functional results

For 9 of the 10 cases in which the diminution of the tuber joint angle did not exceed 10 degrees in comparison with the uninjured foot — i e cases with minimal compression of the calcaneus — the functional results were favourable If we consider the cases with considerable compression as expressed by a diminution of the tuber joint angle in comparison with the healthy side of more than 30 degrees we find favourable functional results for 7 out of 20 or 35 0 % The mean diminution of the tuber-joint angle in comparison with the uninjured foot at follow up is largest for the group with least favourable (poor) results These results merely confirm our previous observation that a higher degree of compression of the bone as measured by the tuber joint angle coincides with less favourable functional results

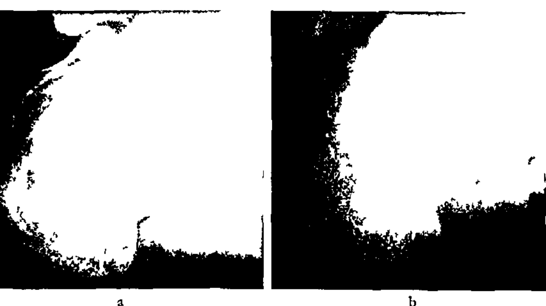
Arthrosis of the subtalar joint

The roentgenologic evidence of arthrosis of the subtalar joint with consequent deformity consists in narrowing of the joint space marginal osteophytes and structural changes in the adjacent bone In the present series evaluation of this factor has presented a problem mainly because these fractures are associated with initial deformity of the posterior articular facet Diagnosis and evaluation of changes due to arthrosis is fraught with difficulties even if entirely satisfactory roentgenograms are available Especially useful is projection I of Broden which provides a fairly reliable picture of marginal osteophytes With these projections we were able to demonstrate marginal excrescences suggestive of oesteophytes in almost two thirds of the series by comparing the injured and uninvolved foot



a b

Fig 15 Results (b) 7 years after original injury (a) treated by eexcercise only (non followed up)



a b

Fig 16 Case no 33 At time of injury (a) at follow up 4 years later (b) Projection 1

Any displacement of the posterior articular surface has on the whole persisted in this series, but in the majority of cases the notch on the articular facet is less sharply outlined, indicating reorganization of this area (fig 15 and 16)

Other objective findings

The calcaneo-cuboid joint In 11 of the 90 cases, the original films showed fracture lines entering the calcaneo cuboid joint Six of these cases were classified as unfavourable

Peroneal tendon Four patients had marked tenderness over the peroneus longus tendon behind the lateral malleolus In two of these cases, the roentgenogram showed a marked broadening of the tuber, close to the lateral malleolus All these four patients belonged to the functional group poor

Sensory disturbances In two cases the patients complained of numbness along the lateral border of foot Both showed a marked broadening of the heel and were classified as poor

Oedema About 25 % of the patients complained of swelling of the injured foot with exertion Due to the fact that the follow up examinations were performed at different hours of the day, it was difficult to obtain comparable measurements Nearly all the cases complaining of this symptom belonged to those classified as poor

Healing All cases showed roentgenological signs of healing No case of thrombosis or other complication was recorded

C Bilateral intra articular fractures of the calcaneus

In 1952 a 42 year old man was treated at the Surgical Department of Akademiska Sjukhuset in Uppsala for bilateral fracture of the calcaneus One side was treated by *early exercises* the *opposite side* by *plaster fixation* The functional results in this case were considerably better for the fracture treated by exercise therapy than on the side which had been immobilized in plaster Earlier studies have established that poor functional results are obtained for bilateral fractures of the calcaneus with serious joint involvement, regardless of the form of treatment Both our experience with the aforementioned case and earlier experiences made us decide at the beginning of this investigation that in all cases of bilateral intra articular fracture one side would be subjected to early exercise therapy while the other side would be treated by plaster fixation or operation It was further decided that the side which from the roentgenograms presented the more serious injury would become the subject for exercise therapy During the period covered by this investigation a total of 8 cases of bilateral fracture with serious joint involvement presented In the majority of these cases the tuber joint angle was on both sides obliterated or negative In two cases both feet were treated by exercise therapy for different reasons * Of the 6 remaining cases 3 were treated by unilateral plaster fixation and the other 3 by arthrodesis One of the latter cases was still undergoing treatment at the time of follow up and has consequently not been included in the follow up series Thus 5 cases remain in which one side was treated by early exercises while the other side was immobilized in plaster or subjected to arthrodesis On follow up all 5 cases *subjected to this treatment presented unfavourable functional results* The subjective symptoms were in all cases severe On the whole though the symptoms were less pronounced on the side which had been subjected to exercise therapy All 5 patients were occupationally handicapped, one of them to the extent that occupational rehabilitation was required Four of the 5 cases were insured and received benefits for disability rated at 15—33¹/₃ % The objective evidence concerning mobility of the talo crural and subtalar joints muscular atrophy, gait etc, failed to establish any clear difference between feet treated with exercise plaster fixation, or operation

Widen reports equally poor results from his series with the exception of one case This was a 14 year old boy with bilateral fractures which were both treated by operation In this case full recovery of function resulted Moberg s series (p 86) of patients treated by arthrodesis includes 4 cases in which operation was performed bilaterally These all present *poor functional results and permanent disability*

* One of these was not followed up

CHAPTER 8

Factors of Prognostic Relevance with respect to Follow-up Results

At the time of admission to hospital the following factors were recorded fracture group (p 42) type of fracture (p 42), age and sex (p 43), tuber-joint angle in the injured foot (p 36), diminution of the tuber joint angle as compared to the injured foot (p 37), and degree of displacement of the posterior articular surface (p 37)

The following analysis is intended to determine the relevance of these factors with respect to certain variables characterizing the follow up results, i e functional results, gait, muscular atrophy mobility of the sub talar and talocrural joints and residual disability entitled to insurance benefits

Since our follow up investigation had established that functional results were consistently favourable for extra articular fractures assigned to groups I—IV, these were excluded from the present evaluation Also excluded were the 6 patients with bilateral calcaneal fractures and involvement of the articular surfaces on both sides which formed a separate group Of the 90 cases of unilateral intra articular fractures comprising the comparative series the 13 cases placed in fracture group V to some extent form a special class They will be accounted for in tables 20 and 21 only and are excluded from the further analysis As roentgenologic data were incomplete for two cases belonging to groups VI and VII, the comparative series is for the purpose of this evaluation restricted to 75 cases

Men and women will be accounted for separately In the introductory tables one factor at a time has been correlated both with the subjective functional results and with the follow up results For the factors found to have a strong bearing on the follow up results, subsequent tables present a more detailed analysis

Relevance of fracture group and type of fracture

The difference between fracture groups VI and VII lies in the more lateral orientation of the shearing fracture in the former group with

compression mainly involving the lateral portion of the posterior articular surface In the cases assigned to group VII the shearing fracture strikes the posterior articular surface further medially, producing depression of the greater portion of the posterior articular surface in relation to the medial fragment A feature common to both fracture groups is displacement of the posterior articular facet in contrast to group V in which the shearing fracture runs into the articular surface without causing any displacement

Table 20 shows the distribution of cases with respect to fracture group sex and functional results

Table 20 Distribution of cases with respect to fracture group sex and functional results

Functional results	Men			Women		
	Group V	Group VI	Group VII	Group V	Group VI	Group VII
Excellent	11	8	5	1	5	1
Good	1	13	6		4	1
Fair		11	5		1	1
Poor		7	6		1	
Total	12	39	22	1	11	3

From this table group V stands out by its uniformly favourable functional results As regards the other two fracture groups no appreciable difference can be discerned in the functional results for either sex

It appears therefore that there is no demonstrable difference between fracture groups VI and VII with respect to the functional results Prognosis for fracture group V is significantly (*) better than for fracture groups VI and VII

The figures presented in table 21 indicate the relative frequency of favourable follow up results as defined above in the relevant fracture groups No distinction as to sex is made

The designations Excellent and Good functional results have been defined earlier (p 48), as having 'Normal gait (p 52) The designation No muscular atrophy implies that a decrease in the girth of the calf muscles not exceeding 1 cm in comparison with the uninjured side was accepted Normal mobility of the subtalar joint and Normal mobility of the talocrural joint indicate that the deviation from the range of movement in the uninjured foot did not exceed 5 degrees

We find from this table that all variables are consistently more favourable for the cases assigned to group V than for the other groups The difference between group V on the one hand and groups VI and VII on

Table 21 Relative frequency (percentage) of favourable follow up results as represented by certain characteristics within the subgroups differentiated by fracture group

Characteristic of follow up results	Group V		Group VI		Group VII	
	Characteristic/ subgroup	%	Characteristic/ subgroup	%	Characteristic/ subgroup	%
Excellent+good functional results	13/13	100	30/50	60.0	13/25	52.0
Normal gait	12/13	92.3	37/50	74.0	16/25	64.0
No muscular atrophy	13/13	100	38/46	82.8	16/24	66.7
Normal mobility of subtalar joint	11/13	84.6	15/50	30.0	9/25	36.0
Normal mobility of talocrural joint	12/13	92.3	34/50	68.0	14/25	56.0
No residual disability entitling insurance benefits	4/4	100	19/29	65.5	10/13	76.9

the other is significant both with respect to the percentage of excellent and good functional results (*) and for normal mobility of the subtalar joint (**) These results further justify the dissociation of group V from groups VI and VII as has been done in the following tables Group VI and VII, on the other hand present no material difference with respect to any of the result variables

Table 22 shows the distribution of cases with respect to functional results and sex when the series is differentiated into Palmer s (1948) fracture types 1 and 2 Both in this table and those to follow, the cases comprising group V have been excluded for the reasons stated above

We may conclude from this table that the male group presents no appreciable differences As for the women, favourable functional results are found in all cases classified as type 1 fractures but it should be noted that the number of cases is insufficient to permit any definite conclusions The difference is probably significant ( )

Functional results	Men		Women	
	Type 1	Type 2	Type 1	Type 2
Excellent	8	5	6	
Good	13	6	4	1
Fair	10	6		2
Poor	10	3		1
Total	41	20	10	4

Table 22 Distribution of cases with respect to type of fracture sex and functional results

Table 23 Relative frequency (percentage) of favourable follow up results as represented by certain characteristics within the subgroups differentiated by type of fracture

Characteristic of follow up results	Fracture type 1		Fracture type 2	
	Characteristic/subgroup		Characteristic/subgroup	
Excellent+good functional results	31/51	60.8	12/24	50.0
Normal gait	36/51	70.6	17/24	70.8
No muscular atrophy	37/47	78.7	17/23	73.9
Normal mobility of subtalar joint	18/51	35.3	6/24	25.0
Normal mobility of talocrural joint	32/51	62.7	16/24	66.7
No residual disability entitling insurance benefits	22/30	73.3	7/12	58.3

Table 23 presents the relative frequency of favourable follow up results when the series is differentiated into type 1 and type 2 fractures but undistinguished as to sex.

It can be concluded *from this table that there is no appreciable difference* between type 1 and type 2 fractures with respect to any of the result variables.

Relevance of age and sex

Widen (1954) found in his series of operated patients a certain difference in the results with respect to the age of the patient. With the age limit in his series set at 50 satisfactory functional end results for 77.4 % of cases in the younger age groups as against 52.0 % for patients over 50 years of age implying a statistically significant difference. Essex Lopresti (1952) claiming that operation produced poor end results in patients over 50 advocated early active exercise for these elderly patients.

Table 24 shows the functional results for men and women differentiated into several age groups. All 75 cases are included in fracture groups VI or VII.

Of the 14 women included in this series 11 showed favourable functional results. The corresponding figures for men are 61 and 32 respectively. This does not amount to a statistically significant difference.

If we divide the series into two age groups with the limit set at 50 we find favourable functional results for 9 out of the 10 older women (over 50 years of age) as against 2 out of 4 in the group of younger women. It is possible that this represents a random difference but the number of cases is too small to warrant any definite conclusions concern

Table 24 Distribution of cases with respect to age sex and functional results

Functional results	Age in years and sex																						Number of cases
	< 26		26 – 30		31 – 35		36 – 40		41 – 45		46 – 50		51 – 55		56 – 60		61 – 65		66 – 70		> 70		
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	
Excellent	–	–	2	–	–	–	2	–	2	1	3	–	3	2	1	2	–	–	–	1	–	–	19
Good	–	–	–	1	1	–	3	–	2		4	–	4		4		–	1	1	–	–	3	24
Fair	1	–	2	–	1	–	2	–	2	–	1	1	2	–	4		1		–	1	–	–	18
Poor	–	–	–	–	2	–	2	1	1	–	2	–	1	–	4	–	1	–	-	-	–	–	14
Total	1	–	4	1	4	–	9	1	7	1	10	1	10	2	13	2	2	1	1	2	-	3	75

Summary of table 24

Functional results	Men		Women	
	< 50 years	> 50 years	< 50 years	> 50 years
Excellent	9	4	1	5
Good	10	9	1	4
Fair	9	7	1	1
Poor	7	6	1	-
Total	35	26	4	10

ing the relevance of the age factor An alternative explanation of the favourable functional results for elderly women may be that their activities are more restricted in comparison with both the younger women and the older male group, and their functional requirements thus lower

If we review the results in the male series we find favourable functional results in 19 out of the 35 men of 50 years or younger which amounts to 54 3 % In the group over 50 exactly half of the men, or 13 out of 26 showed favourable functional results The difference has no statistical significance If we set the age limit at 46 we find favourable functional results for 48 0 % of the younger men and 55 5 % of the older age group This difference also falls short of statistical significance and we may therefore concluded that the present material provides no evidence to suggest that the age factor is of decisive importance as regards men

With the age factor accounted for no significant difference can be demonstrated between the sexes Nevertheless the observed differences are sufficiently large to warrant a differentiation according to sex in the following account

Table 25 Relative frequency (percentage) of favourable follow up results as represented by certain characteristics within the subgroups differentiated by age

Characteristic of follow up results	50 years and younger		Over 50 years	
	Characteristic/subgroup		Characteristic/subgroup	
Excellent+good functional results	21/39	53 8	22/36	61 1
Normal gait	29/39	74 4	24/36	66 7
No muscular atrophy	29/38	76 3	25/32	78 1
Normal mobility of subtalar joint	15/39	38 5	9/36	25 0
Normal mobility of talocrural joint	29/39	74 4	19/36	52 8
No residual disability entitling insurance benefits	16/25	64 0	13/17	76 5

Table 25 illustrates what bearing age has on the variables characterizing the follow up results No distinction of sex is made

We may conclude from this table that there is no appreciable difference between younger and older patients with respect to the relevant characteristics Not even the largest percentage difference referring to mobility of the talocrural joint, (74 4 % versus 52 8 %) is significant The table tends to support our impression that the demands on function are lower for elderly patients than in the younger age group since the percentage of excellent and good functional results *expressing a relatively* more subjective rating of function is higher among the older patients whereas variables permitting a more objective grading specifically normal gait and normal mobility of the subtalar and talocrural joints show a higher percentage in the younger age groups

Relevance of the tuber joint angle

The tuber joint angle as defined earlier is a relative measure of the degree of compression in fractures of the calcaneus, depending on the normal, pre injury value in each individual case

If we divide the series into 3 subgroups according to the size of the tuber joint angle and compare these subgroups with respect to sex and functional results, we obtain the figures set down in table 26

In the male group we find favourable functional results for 22 out of 33 cases with a tuber joint angle exceeding 10 degrees contrasting with an incidence of 10 out of 28 cases with a tuber joint angle of 10 degrees or less The difference is statistically significant ( ) suggesting that this factor does have a bearing upon prognosis

Table 26 Distribution of cases with respect to tuber joint angle at time of injury sex and functional results

Functional results	Tuber joint angle in degrees					
	Men			Women		
	neg −0	1 −10°	>10°	neg −0°	1°−10°	>10°
Excellent	3	1	9		2	4
Good	1	5	13	1	1	3
Fair	4	5	7		1	1
Poor	7	2	4			1
Total	15	13	33	1	4	9

Table 27 presents the relative frequency of favourable follow-up results in the subgroups differentiated according to tuber-joint angle No distinction of sex is made

If we disregard the insurance cases without residual disability, we find that the table presents a uniform tendency for all result variables in that the incidence of favourable results increases with a higher value for the tuber joint angle A comparison of the group presenting a tuber joint angle exceeding 10 degrees with at the other extreme the cases in which the tuber-joint angle is zero or negative yields significant ( ) differences with respect to the percentage of excellent and good functional results, normal gait and absence of muscular atrophy, while the differences for normal mobility of the subtalar and talocrural joints emerge as clearly significant (**)

Table 27 Relative frequency (percentage) of favourable follow up results as represented by certain characteristics within the subgroups differentiated by the tuber joint angle at time of injury

Characteristics of follow up results	Tuber joint angle in degrees					
	Neg −0°		1 −10°		>10°	
	Characteristic/ subgroup	%	Characteristic/ subgroup		Characteristic/ subgroup	
Excellent+good functional results	5/16	31 3	9/17	52 9	29/42	69 0
Normal gait	7/16	43 8	11/17	64 7	35/42	83.3
No muscular artophy	6/13	46 2	13/17	76 5	35/40	87 5
Normal mobility of subtalar joint	0/16	0	2/17	11 8	22/42	52 4
Normal mobility of talocrural joint	6/16	37 5	8/17	47 1	34/42	81 0
No residual disability entitling insurance benefits	6/9	66 7	3/7	42.9	20/26	76 9

Relevance of diminuted tuber joint angle in comparison with the uninjured foot

Roentgenograms of the uninjured foot had at some point during our investigation been taken in all cases included in the present analysis which permitted us to define any diminution of the tuber joint angle in relation to the uninjured side Since individual variations of the normal value range from 20 to as much as 45 degrees one might expect this measure to provide a more reliable indication of the degree of compression of the fractured calcaneus than the one value for the tuber joint angle in the injured foot only

We found in a previous section (p 62) that functional results in cases with widely differing values for the tuber joint angle in the fractured and uninjured foot were somewhat less favourable than in cases with only slightly varying values This difference was not statistically significant however

In table 28 the series has been divided into two subgroups according to the degree of diminution of the tuber joint angle in comparison with the uninjured foot with the limit set at 20 degrees and this value has been correlated to the functional results In this instance too the series has been differentiated by sex

We find from this table that functional results were favourable for somewhat less than half of the men or 14 out of 32 with diminution of the tuber joint angle exceeding 20 degrees Of the 29 men with a diminution of the tuber joint angle of 20 degrees or less 18 had favourable functional results A certain difference does exist consequently but it has no statistical significance For the women we find favourable functional results in all 3 cases presenting a diminution of the tuber joint angle exceeding 20 degrees while of the 11 cases with a diminution of 20 degrees or less 8 presented favourable functional results

Table 28 Distribution of cases with respect to initial diminution of tuber joint angle in comparison with uninjured foot sex and functional results

Functional results	Initial diminution in comparison with uninjured foot			
	Men		Women	
	≤ 20°	> 20°	≤ 20°	> 20°
Excellent	7	6	5	1
Good	11	8	3	2
Fair	7	9	2	
Poor	4	9	1	
Total	29	32	11	3

The above results indicate that diminution of the tuber-joint angle in comparison with the uninjured foot, as a measure of the degree of compression of the calcaneus, does not constitute a decisive factor with respect to the functional results

Table 29 shows the relative frequency of favourable follow-up results within the two subgroups differentiated by the degree of diminution of the tuber joint angle

Table 29 Relative frequency (percentage) of favourable follow up results as represented by certain characteristics within the subgroups differentiated by initial diminution of tuber joint angle in comparison with the uninjured foot

Characteristic of follow up results	Initial diminution in comparison with uninjured foot			
	≦ 20		> 20°	
	Characteristic/ subgroup	%	Characteristic/ subgroup	%
Excellent+good functional results	26/40	65 0	17/35	48 6
Normal gait	32/40	80 0	21/35	60 0
No muscular atrophy	34/38	89 5	20/32	62 5
Normal mobility of subtalar joint	18/40	45 0	6/35	17 1
Normal mobility of talocrural joint	31/40	77 5	17/35	48 6
No residual disability entitling insurance benefits	15/21	71 4	14/21	66 7

We can in this table discern a significant (*) difference with respect to the result variables referring to muscular atrophy and mobility of the subtalar and talocrural joints The value for the tuber joint angle in the fractured foot (table 27) appears to have greater prognostic relevance than the diminution of the tuber joint angle in comparison with the uninjured foot (table 29)

Relevance of displacement of the posterior articular surface

Both at the time of injury and at follow up all cases included in the present series were subjected to roentgenographic examination with Broden s oblique projections providing a basis for evaluating any displacement of the posterior articular surface A relatively moderate depression of the posterior articular facet, as measured by the tuber joint angle does not exclude the possibility of a considerable displacement of the posterior

articular surface As appears from the chapter on roentgenologic procedure (p 37) it has been impossible to express the degree of displacement in exact numerical values and the series has for the purpose of this evaluation been divided into two subgroups marked by moderate displacement and considerable displacement respectively The distribution of cases within the subgroups is illustrated by table 30

Table 30 Distribution of cases with respect to degree of displacement sex and functional results

Functional results	Degree of displacement			
	Men		Women	
	Moderate displacement (+)	Considerable displacement (++)	Moderate displacement (+)	Considerable displacement (++)
Excellent	12	1	3	3
Good	14	5		
Fair	3	13	1	1
Poor	2	11		1
Total	31	30	9	5

The table shows that 26 out of the 31 men with moderate displacement (+), or 83 9 % presented favourable results as against only 20 0 % or 6 out of the 30 men with considerable displacement (++) It is evident that there is a material difference between the two groups with respect to the functional results The differences are statistically significant (***)

As for the women the number of cases is again insufficient to warrant any conclusions We may note however that functional results were favourable for all but one of the cases with moderate displacement

The high degree of correlation between degree of displacement and functional results which emerges from this table is fully consistent with the uniformly favourable functional results presented by patients in fracture group V As we know these fractures are characterized by the absence of displacement of the posterior articular facet In view of the favourable functional results for group V patients it seems reasonable to assume that the degree of displacement must be the decisive factor The results presented in the above table undoubtedly provide a strong indication that this factor has a bearing upon prognosis

Table 31 shows the relative frequency of favourable follow up results in the two subgroups differentiated by the degree of displacement

Table 31 Relative frequency (percentage) of favourable follow up results as represented by certain characteristics within the subgroups differentiated by the degree of displacement

Characteristic of follow up results	Degree of displacement			
	Moderate (+)		*Considerable (++)*	
	Characteristic/ subgroup	%	Characteristic/ subgroup	
Excellent+good functional results	34/40	85.0	9/35	25.7
Normal gait	37/40	92.5	16/35	45.7
No muscular atrophy	36/38	94.7	18/32	56.3
Normal mobility of the subtalar joint	20/40	50.0	4/35	11.4
Normal mobility of the talocrural joint	33/40	82.5	15/35	42.9
No residual disability entitling insurance benefits	18/23	78.3	11/19	57.9

We find from this table that the difference between the two subgroups is most marked with respect to the percentage of excellent and good functional results (85.0 % — 25.7 % = 59.3 %) (***) With the exception of residual disability entitling one to insurance benefits, the differences are also strongly significant (***) for the remaining result variables It would seem that the degree of displacement has a stronger bearing upon prognosis than any of the other factors which have been taken into account

In the preceding sections we have estimated the correlation between on the one hand functional results and favourable follow-up results as characterized by excellent and good functional results normal gait absence of muscular atrophy normal mobility of the subtalar joint normal mobility of the talocrural joint, and absence of residual disability entitling one to insurance benefits and, on the other hand each one of the following factors fracture group type of fracture, age and sex absolute value of tuber joint angle diminution of tuber-joint angle in comparison with the uninjured foot and degree of displacement of the posterior articular facet We shall now proceed to analyze the functional follow up results with respect to certain combinations of the above mentioned factors Since the degree of displacement emerged definitely as the most relevant factor, the series has been differentiated by this criterion No distinction as to sex is made

It is evident from table 32 that within the subgroup characterized by moderate displacement (+) no appreciable differences exist with respect to age fracture group and type of fracture diminution of tuber joint angle

Table 32 Functional results correlated with age fracture group type of fracture initial diminution of tuber joint angle in comparison with the uninjured foot, and absolute tuber joint angle in fractured foot in cases with

moderate displacement (+)

Functional results	Age in years		Fracture group		Type of fracture		Initial diminution of tuber joint angle		Tuber joint angle in fractured foot		Total cases
	<50	>50	VI	VII	1	2	<20	>20	<10°	>10°	
Excellent	9	6	10	5	10	5	10	5	3	12	15
Good	7	12	14	5	14	5	14	5	5	14	19
Fair	3	1	3	1	1	3	3	1	1	3	4
Poor	2	0	2	0	2	0	1	1	1	1	2
Total	21	19	29	11	27	13	28	12	10	30	40

Table 33 Functional results correlated with age fracture group type of fracture initial diminution of tuber joint angle in comparison with the uninjured foot and absolute tuber joint angle in the fractured foot in cases with

considerable displacement (+ +)

Functional results	Age in years		Fracture group		Type of fracture		Initial diminution of tuber joint angle		Tuber joint angle in fractured foot		Total cases
	<50	>50	VI	VII	1	2	<20°	>20	≤10°	>10	
Excellent	1	3	3	1	4	0	2	2	3	1	4
Good	4	1	3	2	3	2	0	5	3	2	5
Fair	7	7	9	5	9	5	6	8	9	5	14
Poor	6	6	6	6	8	4	4	8	8	4	12
Total	18	17	21	14	24	11	12	23	23	12	35

in comparison with the uninjured foot and tuber-joint angle in the fractured foot From table 33 we find that the same observation holds true for the cases presenting a considerable degree of displacement (+ +)

If the degree of displacement is adopted as a basis for prognosis with respect to the functional (follow up) results data on the other factors are of no account Not even the tuber joint angle in the fractured foot a factor which in the preceding analysis (table 26) was found to be significant appears to have any tendency to influence prognosis

This is explained by the correlation existing between the degree of displacement and the absolute value for the tuber-joint angle as is evident from tables 32 and 33

These 30 out of the 40 cases with moderate displacement (+), or 75 0 %, present a value for the tuber joint angle exceeding 10 degrees, as against 12 out of 35 cases (or 34 3 %) with considerable displacement (++) The difference (75 0 % — 34 3 % = 40 7 %) is statistically significant (**)

Similarly we find from the tables that 70 0 % of cases with moderate displacement present a diminution of the tuber joint angle in comparison with the uninjured foot of 20 degrees or less, as against an incidence of 12 out of 35 (34 3 %) of the cases with considerable displacement This difference, too is significant

We may now proceed to study the relevance of the remaining factors within subgroups with the same degree of displacement In tables 34 and 35 we find the relative frequency of favourable follow up results, as

Table 34 Relative frequency and percentage of favourable follow up results as represented by certain characteristics within different factor group in cases with *moderate displacement* (+)

Characteristic of follow up results	Factor group									
	Age in years		Fracture group		Type of fracture		Initial diminution of tuber joint angle		Tuber joint angle in fractured foot	
	< 50	> 50	VI	VII	1	2	≤ 20°	> 20°	< 10°	> 10°
Excellent + good functional results	16/21 76 2	18/19 94 7	24/29 82 8	10/11 90 9	24/27 88 9	10/13 76 9	24/28 85 7	10/12 83 3	8/10 80 0	26/30 86 7
Normal gait	19/21 90 5	18/19 94 7	27/29 93 1	10/11 90 9	24/27 88 9	13/13 100	26/28 92 9	11/12 91 7	9/10 90 0	28/30 93.3
No muscular atrophy	19/20 95 0	17/18 94 4	26/27 96 3	10/11 90 9	25/26 96 2	11/12 91 7	25/26 96 2	11/12 91 7	9/10 90 0	27/28 96 4
Normal mobility of subtalar joint	11/21 52 4	9/19 47 4	13/29 44 8	7/11 63 6	14/27 51 9	6/13 46 2	17/28 60 7	3/12 25 0	2/10 20 0	18/30 60 0
Normal mobility of talocrural joint	20/21 95 2	13/19 68 4	26/29 89 7	7/11 63 6	21/27 77 8	12/13 92 3	25/28 89 3	8/12 66 7	7/10 70 0	26/30 86 7
No residual disability entitling insurance benefit	10/14 71 4	8/9 88 9	12/16 75 0	6/7 85 7	14/17 82.4	4/6 66 7	13/16 81 3	5/7 71 4	2/4 50 0	16/19 84 2

defined earlier within different factor groups From these tables we may conclude among other things that the age factor presents an appreciable difference only with respect to normal mobility of the talocrural joint In both subgroups the frequency of normal mobility in this respect is somewhat higher in the younger age group than in the older group This difference does not have statistical significance however

Not the slightest tendency towards appreciable differences with respect to any of the result variables can be discerned for the different fracture groups or for the different types of fracture

With regard to the tuber joint angle we note a lower incidence of muscular atrophy when the diminution of this angle in comparison with the uninjured foot does not exceed 20 degrees The difference is not statistically significant Otherwise the subgroups differentiated by tuber-joint

Table 35 Relative frequency and percentage of favourable follow up results as represented by certain characteristics within different factor group in cases with *considerable displacement* (+ +)

Characteristic of follow up results	Factor group									
	Age in years		Fracture group		Type of fracture		Initial diminution of tuber joint angle		Tuber joint angle in fractured foot	
	< 50	> 50	VI	VII	1	2	< 20°	> 20°	≤ 10	> 10
Excellent + good functional results	5/18 27.8	4/17 23.5	6/21 28.6	3/14 21.4	7/24 29.2	2/11 18.2	2/12 16.7	7/23 30.4	6/23 26.1	3/12 25.0
Normal gait	10/18 44.4	6/17 35.3	10/21 47.6	6/14 42.9	12/24 50.0	4/11 36.4	6/12 50.0	10/23 43.5	9/23 39.1	7/12 58.3
No muscular atrophy	10/18 55.6	8/14 57.1	12/19 63.2	6/13 46.2	12/21 57.1	6/11 54.5	9/12 75.0	9/20 45.0	10/20 50.0	8/12 66.7
Normal mobility of subtalar joint	4/18 22.2	0/17 0	2/21 9.5	2/14 14.3	4/24 16.7	0/11 0	1/12 8.3	3/23 13.0	0/23 0	4/12 33.3
Normal mobility of talocrural joint	9/18 50.0	6/17 35.3	8/21 38.1	7/14 50.0	11/24 45.8	4/11 36.4	6/12 50.0	9/23 39.1	7/23 30.4	8/12 66.7
No residual disability entitling insurance benefits	6/11 54.5	5/8 62.5	7/13 53.8	4/6 66.7	8/13 61.5	3/6 50.0	2/5 40.0	9/14 64.3	7/12 58.3	4/7 57.1

Table 38 Relative frequency and percentage of favourable follow up results as represented by certain characteristics within different factor group in cases with *tuber joint angle of 10 degrees or less* (at time of injury)

Characteristic of follow up results	Factor group: Age in years		Fracture group		Type of fracture		Initial diminution of tuber joint angle		Degree of displacement	
	≦ 50	> 50	VI	VII	1	2	≦ 20°	> 20	(+)	(++)
Excellent + good functional results	6/13 46 2	8/20 40 0	8/18 44 4	6/15 40 0	8/18 44 4	6/15 40 0	3/5 60 0	11/28 39 3	8/10 80 0	6/23 26 1
Normal gait	8/13 61 5	10/20 50 0	10/18 55 6	8/15 53 3	9/18 50 0	9/15 60 0	4/5 80 0	14/28 50 0	9/10 90 0	9/23 39 1
No muscular atrophy	7/13 53 8	12/17 70 6	11/16 68 8	8/14 57 1	10/15 66 7	9/15 60 0	5/5 100	14/25 56 0	9/10 90 0	10/20 50 0
Normal mobility of subtalar joint	2/13 15 4	0/20 0	1/18 5 6	1/15 6 7	0/18 0	2/15 13 3	1/5 20 0	1/28 3 6	2/10 20 0	0/23 0
Normal mobility of talocrural joint	7/13 53 8	7/20 35 0	8/18 44 4	6/15 40 0	6/18 33 3	8/15 53 3	3/5 60 0	11/28 39 3	7/10 70 0	7/23 30 4
No residual disability entitling insurance benefits	2/7 28 6	7/9 77 8	4/9 44 4	5/7 71 4	5/8 62 5	4/8 50 0	0/0	9/16 56.3	2/4 50 0	7/12 58 3

variation apparent in both tables can be claimed to add up to a significant *difference between moderate and considerable displacement for these two variables*

The remaining factors (age fracture group type of fracture and diminution of tuber-joint angle in comparison with the uninjured foot) yield no significant differences which means that the observations resulting from tables 36 and 37 are consistent with the impression we received from tables 38 and 39

From the preceding analysis of factors to be taken into account in the primary evaluation of fractures of the calcaneus in terms of clinical management we may conclude that the degree of displacement of the posterior articular surface is the decisive factor in this respect the degree

Table 39 Relative frequency and percentage of favourable follow up results as represented by certain characteristics within different factor group in cases with *tuber joint angle exceeding 10 degrees* (at time of injury)

Characteristic of follow up results	Factor group: Age in years		Fracture group		Type of fracture		Initial diminution of tuber joint angle		Degree of displacement	
	<50	>50	VI	VII	1	2	<20°	>20°	(+)	(++)
Excellent+ good functional results	15/26 57 7	14/16 87 5	22/32 68 8	7/10 70 0	23 33 69 7	6 9 66 7	23 35 65 7	6 7 85 7	26/30 86 7	3 12 25 0
Normal gait	21/26 80 8	14/16 87 5	27/32 84 4	8/10 80 0	27 33 81 8	8 9 88 9	28 35 80 0	7/7 100	28 30 93 3	7/12 58 3
No muscular atrophy	22/25 88 0	13/15 86 7	27/30 90 0	8 10 80 0	27/32 84 4	8 8 100	29/33 87 9	6/7 85 7	27/28 96 4	8/12 66 7
Normal mobility of subtalar joint	13/26 50 0	9/16 56 3	14/32 43 8	8/10 80 0	18/33 54 5	4/9 44 4	17/35 48 6	5/7 71 4	18/30 60 0	4/12 33 3
Normal mobility of talocrural joint	22/26 84 6	12/16 75 0	26/32 81.3	8/10 80 0	26/33 78 8	8 9 88 9	28/35 80 0	6/7 85 7	26/30 86 7	8/12 66 7
No residual disability entitling insurance benefits	14/18 77 8	6/8 75 0	15/20 75 0	5/6 83.3	17/22 77.3	3/4 75 0	15/21 71 4	5/5 100	16/19 84 2	4/7 57 1

of compression of the fracture as measured by the tuber-joint angle in the fractured foot only ranking second in importance Neither the age of the patient on the one hand nor fracture group or type of fracture appear to be of decisive importance The fact that the degree of displacement is the decisive factor implies that our evaluation of these fractures can be based on reliable roentgenographic evidence The personal opinion of the author is that the degree of displacement is best visualized with Broden s projection I

CHAPTER 9

Comparison with Other Series

Impartial evaluation and comparison of the therapeutic results of different fracture series represents a major problem The many variations presented by fractures of the calcaneus and their divergent classification do not always permit comparison of different series The criteria for evaluation may likewise vary between different series A case which one author might class as good may be graded as fair by another In the majority of studies the follow up results are based on a personal follow up examination, but occasionally they are derived from a combination of personal investigations and questionnaires Undoubtedly different series vary with respect to the severity of the fractures since a number of hospitals have practiced selection of their material In addition, it is likely that the results are to some extent influenced by the length and the period to which collection and treatment of the series are referable In a number of series the results are derived from evaluation for insurance purposes only Due to the wide variety of regulations in this respect a comparison of certain series is feasible only within one and the same country There is a fairly wide divergence of opinion between different series as to what constitutes an adequate follow up period In order to ensure a fair and objective comparison of the results in different series, therfore, the following requirements should be satisfied

1 The series should be referable to approximately the same period of time
2 The series should be equated with respect to such variables as may influence prognosis
3 Classification of the series should permit comparison of the fractures with respect to their severity
4 Unless the length of the follow up period is found to be irrelevant to prognosis this factor should not present substantial differences and should perferably be equated
5 Evaluation of the functional results should be based on similar critera

As has been stressed in a previous section, our interest is primarily directed towards intra articular fractures which present varying functional results following different forms of treatment in different series In the following section is presented a comparison between the present series as representing treatment by early exercise and two other series subjected to operative treatment To date the largest series of fractures of the calcaneus treated by open reduction has been published by Widen in 1954 Comparison with his series is greatly facilitated by the fact that classification and follow up procedure in the present series are set up along similar lines *The second comparison will be based on cases treated* by triple arthrodesis included in the series published by Moberg in 1953 For the purpose of the present comparison some additions have been made to the series For reasons which will be discussed in a later section comparison with this series will be limited to results derived from evaluation for insurance purpose

With a view to ensuring an optimal degree of objectivity in our comparisons the series will be differentiated by the size of the tuber-joint angle Because of technical difficulties in connection with roentgenographic evaluation it proved unfeasible to differentiate the series according to the degree of displacement of the posterior articular surface as would have been preferable On the other hand a significant correlation was established in a previous chapter between the size of the tuber joint angle and the functional results

In 1954 Widen published the results of a follow up study of 132 patients with fracture of the calcaneus His series was derived from two Stockholm hospitals and consisted of patients treated during the years 1944—1950 Part of the series had been referred for treatment by other Stockholms hospials As appears from table 40 intra articular fractures of the calcaneus (groups VI—VII) were for the greatest part treated by open reduction according to Palmer s method Widen s tabular presentation of the series provides data on age and sex distribution classification of fractures tuber joint angle at time of injury and at follow up and in the majority of cases permits an estimation of the diminution of the tuber-joint angle in relation to the uninjured foot No data is available, on the other hand on the degree of displacement of the posterior articular surface prior to follow up The follow up results in Widen s series which permit comparison with the present series are the following degree of function gait muscular atrophy mobility of the subtalar and talocrural joints and results as evaluated for insurance purposes

Table 40 Distribution of cases comprising Widén's, Moberg's and present series with respect to fracture group, form of treatment, unilateral and bilateral involvement, and unilateral involvement associated with other disabling injuries

Fracture series			Fracture group I–IV	Fracture group V	Fracture group VI–VII	Total cases	Insured cases included in groups VI–VII
Widén	Open reduction	Unilateral fractures	—	—	56	56	33
		Bilateral fractures	—	—	6	6	
		Unilateral fractures with concomitant injuries	—	—	3	3	
	Other operative treatment or conservative treatment	Unilateral fractures	31	20	13	64	
		Bilateral fractures	—	—	1	64	
		Unilateral fractures with concomitant injuries	—	2	—	2	
Department I of Sahlgrenska Sjukh.	Moberg: Reduction + triple arthrodesis in two stages	Unilateral fractures	—	—	26	26	22
		Bilateral fractures	—	—	4	4	
		Unilateral fractures with concomitant injuries	—	—	3	3	
	Other operative treatment or conservative treatment	Unilateral fractures	9	3	48	60	
		Bilateral fractures	5	—	1	6	
		Unilateral fractures with concomitant injuries	4	—	7	11	
Present series	Early exercise therapy	Unilateral fractures	17	13	77	107	42
		Bilateral fractures	—	—	1	1	
		Unilateral fractures with concomitant injuries	—	2	5	7	
	Plaster fixation or operative treatment	Unilateral fractures	—	—	1	1	
		Bilateral fractures	—	—	5	5	

Specially selected cases.

Moberg and Erfors published in 1953 a preliminary report on the *results of triple arthrodesis in the treatment of intra articular fractures* of the calcaneus This report was based on a series of 15 cases treated by this operation during the years 1947—51 It appeared from this report that while the preliminary results had left a favourable impression the relatively short period of observation did not permit any definitive conclusions to be drawn nor allowed for a final evaluation of results from the insurance point of view The author has been fortunate in being allowed to study the relevant material which has been enlarged by additional cases treated by triple arthrodesis up to and including 1955 at Surgery Department I at Sahlgrenska Sjukhuset during the years 1947—55 a total of 110 patients were admitted with fractures of the calcaneus Tables 40 and 41 illustrate the distribution in time and the various methods of treatment which have been used for these patients

A review of case records operation reports and roentgenograms *revealed that of the total of 125 fractures treated at Surgery Department* I during the relevant period 98 were intra articular fractures referable to groups V—VII according to Widen s classification Since all case records and with a few exceptions all roentgenograms were available a comparative study provided a reliable classification of this series

The following procedure has been adopted for triple arthrodesis During the first week the injured foot is elevated and a pressure dressing applied to reduce soft tissue edema about the fracture site This is followed by

Table 41 Distribution of fractures of the calcaneus treated at surgical department I of Sahlgrenska Sjukhuset Gothenburg over the period 1947—55

Year	Number of patients	Number of fractures			Form of treatment			
		Intra articular	Extra articular	Total	Arthrodesis	Open reduction	Other operations	Plaster fixation
1947	15	17	1	18	6	—	2	10
1948	7	6	1	7	1	—	—	6
1949	16	17	—	17	7	—	—	10
1950	9	8	2	10	5	—	1	4
1951	11	7	5	12	5	—	—	7
1952	10	9	3	12	3	—	1	8
1953	15	12	6	18	4	3	1	10
1954	11	10	2	12	3	4	—	5
1955	16	12	7	19	3	2	—	14
Total	110	98	27	125	37	9	5	74

closed reduction similar to Bohler's method and percutaneous fixation of the fracture with Rissler nails. Following plaster immobilization for a period of 4—6 weeks, the patient is rehospitalized for the final arthrodesis operation which follows the standard procedure for triple arthrodesis with removal of the cartilage and the articular surfaces between calcaneus, talus, navicular and cuboid bones. Following this second operation, the foot was immobilized in plaster for an additional 12—14 weeks.

Table 41 shows that 37 operations for arthrodesis were performed during the relevant period, in 4 cases bilaterally. A review of the case records discloses that indications for arthrodesis existed in 10 more cases, but was contra indicated for various reasons (residential disqualification, poor general condition of the patients, etc.).

As roentgen analysis with Brodén's projections has been carried out in only a few of Moberg's cases evaluation of the degree of displacement of the posterior articular surface is not feasible. For the majority of cases, on the other hand roentgenograms are available which permit an estimation of the tuber joint angle. Since analysis of the present series in an earlier section has demonstrated a correlation between functional results and tuber-joint angle (p. 71) the series compared here have been differentiated by this criterion. The comparison includes only those cases which are marked in heavy print in table 40 (p. 86), representing unilateral uncomplicated fractures referable to groups VI—VII.

It is evident from table 42, that while the distribution with respect to tuber joint angle is similar for Widén's and Moberg's series, the present series shows a fairly marked disparity. The cases presenting a tuber joint angle exceeding 10 degrees amount in the present series to 56 %, as against 29 % in Widén's series. The difference between these percentages is statistically significant (**). In this respect the present series has an initial advantage. This stresses the necessity of paying particular attention to the differentiation by tuber joint angle in comparing the series with respect

Table 42. Distribution of cases with respect to tuber joint angle at time of injury. Widén's, Moberg's and present series

Series	Tuber joint angle at time of injury			Data missing	Total cases
	neg. –0°	1–10°	>10°		
Widén	24	13	15	4	56
Moberg	12	6	5	3	26
Present series	16	17	42	2	77

to the follow up results For this reason the series will for each comparison be differentiated into three subgroups on the basis of the observed values for the tuber joint angle It might be feared that the operated cases in Widen s series which belong to the group presenting the most favourable values for the tuber joint angle have a far greater incidence of considerable displacement than the present series It should be stressed however that the roentgen technique with which it is possible to identify and evaluate displacement of the posterior articular facet was not adopted until the latter part of 1948 and has at the very most been used in a fourth of that part of Widen s series which is included in the present comparison Analysis of the degree of displacement in relation to the functional results in the present series has furthermore elicited a correlation between the size of the tuber joint angle and the degree of displacement which means that for the purpose of this comparison the value for the tuber joint angle in the injured foot may be substituted for the degree of displacement Thus, within the respective subgroups differentiated by tuber joint angle Widen s and the present series will be considered comparable to a certain degree

It should be stressed however that the degree of displacement has a bearing upon prognosis even after the tuber joint angle has been eliminated as a factor This has been shown in tables 36 37 38 and 39 We may not assume therefore that we have found the ideal solution if we take only the tuber joint angle into account The question arises whether there is any reason to suspect that Widen s series and the present one are at variance with respect to degree of displacement within the subgroups differentiated by tuber-joint angle As appears from tables 36 and 37 *the present series showed a marked correlation between degree of displacement* and tuber joint angle values For Widen s series no record has been made of the initial degree of displacement at the time of follow up (Widen op cit p 71, table 19) The incidence of considerable displacement among the operated cases was found to amount to 65 7 % at follow up

This percentage is derived from the total series of operated cases The *distribution of this series* is illustrated in table 43 which also includes the corresponding figures for the present series

In Widen s series the cases with considerable displacement have not been differentiated by tuber joint angle It should be noted however that the present series shows an entirely different distribution with respect to tuber-joint angle values Since the following analysis is intended to compare the results of the two series within the respective subgroups differentiated by the tuber joint angle the figures of the present series

Table 43 Distribution of fractures with displacement of the posterior articular surface with respect to tuber joint angle at time of injury
Criterion for testing equation of Widen's and present series with respect to degree of displacement

	Tuber joint angle at time of injury			Data Missing	Number of cases	
	Neg.–0°	1°–10°	> 10°			
Widen's Series						
(Operated patients)						
1 Unilateral fractures	26	12	16	4	58	
2. Bilateral fractures	4	3	2	—	9	
Total	30	15	18	4	67	
Considerable (++) displacement at follow up					44	65 7
Present Series						
1 Unilateral fractures	16	17	42	—	75	
Considerable (++) displacement at time of injury	13	10	12	—	35	
Percentage of considerable displacement	81 2	58 8	28 6			46 7
2. Bilateral fractures						
a Treated by early exercise	4	2	1	—	7	
b Treated by plaster fixation or operation	3	1	1	—	5	
Total	7	3	2		12	
Percentage of considerable displacement	100	100	0			83 3 %

should be equated so as to permit comparison with Widen's figures On the basis of the percentage distribution of cases with considerable displacement within the respective tuber joint angle subgroups it is possible to estimate what the percentage of such cases would have been in the present series if this had had the same distribution as Widen's total operated series The following expression is used for this calculation

$$\frac{26 \cdot 81.2\% + 12 \cdot 58.8\% + 16 \cdot 28.6\% + 4 \cdot 100\% + 3 \cdot 100\% + 2 \cdot 0\%}{26 + 12 + 16 + 4 + 3 + 2} = 63.1\%$$

We find that the percentage of 63 1 in the present series is only slightly lower than Widen's percentage of 65 7 Widen's series is obviously at a disadvantage despite the fact that the displacement percentage in his

series refers to the time of follow up and in the present series to the time of injury

It can be expected that the percentage at the time of injury in Widen s series must be higher, since it is reasonable to assume that operation has succeeded in reducing the degree of displacement

Despite this differentiation of the series by tuber joint angle values it is unlikely that the two series are fully equated Initial conditions in Widen s series have been less favourable which should be taken into account when we interpret the results of our analysis

The question arises whether a differentiation according to the diminution of the tuber joint angle in relation to the uninjured foot would have provided a better basis for comparison than the differentiation adopted here based on the value for the tuber joint angle in the injured foot *Further analysis shows that if the distribution of the present series had* been equated to Widen s series with respect to the diminution of the tuber joint angle in relation to the uninjured foot the incidence of displacement in the present series would amount to only 53 6 % as against 65 7 % in Widen s series This fully confirms that the value for the tuber joint angle in the injured foot is the preferable criterion for differentiation

If we wish to evaluate whether the age and sex factors in Widen s Moberg s, and the present series are comparable for the purpose of this analysis we find an average age of 48 45 5 and 48 5 years respectively The age distribution is fairly well equated The percentage of women is somewhat higher in the present series than in the other two (19 % as against 11 % in Widen s and 4 % in Moberg s series)

Widen s series permits a differentiation of the material into fracture groups VI and VII, but this provides an identical percentage distribution with respect to functional results The same is true for the present series

In the following section comparisons will primarily be drawn between the follow up results of Widen s and the present series Comparison will be based on the follow up results presented in Widen s study and the results which have been presented for the present series in the preceding chapters Comparison of Widen s and the present series is as mentioned earlier based on a differentiation of the material into three subgroups representing different values for the tuber joint angle

A *similar comparison with* Moberg s series did not prove *feasible since* his series has not been subjected to follow up examination with the exception of data relevant to insurance adjustment It must be noted that his series though appearing small consits only of about one third of the total patients seen, since only the most severe intra articular fractures are included

Table 44 Functional results in different subgroups Widen s and present series

Functional results	Tuber joint angle					
	Widen s series			Present series		
	neg –0°	1–10°	> 10°	neg –0°	1–10°	> 10°
Excellent	-	4	5	3	3	13
Good	7	4	6	2	6	16
Fair	5	3	3	4	6	8
Poor	5	2	1	7	2	5
Total	24	13	15	16	17	42

Table 44 shows the distribution of Widen s and the present series with respect to the tuber joint angle In Widen s series data on this aspect is missing in 4 cases in the present series in 2 cases

With respect to the length of follow up the two series show considerable variation The average follow up period in Widen s series is considerably longer than in the present series (49 7 months and 27 8 months respectively) From table 45 it appears that the length of follow up is not dependent on the value for the tuber joint angle at the time of injury, nor does any correlation appear between length of follow up and functional results Thus in Widen s series the groups representing excellent and good functional results have an average follow up period of 48 9 months as against 51 2 months for the groups with fair and poor results The corresponding figures in the present series are 27 6 and 28 1 months respectively Within Widen s and the present series the period of obser

Table 45 Average length of observation period in months in different subgroups Widen s and present series

Subgroup	Tuber joint angle at time of injury					
	Widen s series			Present series		
	Neg –0°	1°–10°	> 10°	Neg –0°	1°–10°	> 10°
Entire comparative group	47 0	53 8	50 6	29 1	21 1	30 5
Excellent + good functional results	43 6	5[illegible] 3	51 2	34 9	20 9	19 7
Fair + poor functional results	51 8	51 6	49 0	25 5	21 3	34 6
Normal mobility of subtalar joint	47.3	43 0	52.7		24 5	31 3
Loss of mobility at subtalar joint	46 9	47.3	50 1	29 1	20 6	29 4

vation is on the whole equally long for patients with favourable or unfavourable results

The same observation is made if we compare the length of follow up for cases with normal and impaired mobility of the subtalar joint, respectively, as is evident from table 45

This agreement suggests that the variations with respect to length of follow up between Widen s series and the present series may be disregarded

The percentage of favourable (excellent and good) functional results is somewhat higher in Widén s series than in the present series This holds true for each of the tuber joint angle subgroups The three subgroups differentiated by tuber-joint angle present the following differences

ble 46 Relative frequency and percentage of favourable follow up results as represented by certain iracteristics within the subgroups differentiated by tuber joint angle at time of injury Widén s and present series

Characteristic Follow Up Results	Widén s Series						Present Series					
	Tuber Joint Angle											
	neg —0		1 —10		> 10		neg —0°		1 —10		> 10	
	Characteristic subgroup	%	Characteristic subgroup		Characteristic subgroup		Characteristic subgroup		Characteristic subgroup		Characteristic subgroup	
xcellent + good functional results	14/24	58 3	8/13	61 5	11/15	73 3	5/16	31 3	9/17	52 9	29/42	69 0
ormal gait	16/24	66 7	10/13	76 9	11/15	73 3	7/16	43 8	11/17	64 7	35/42	83 3
o muscular atrophy	16/20	80 0	8/12	66 7	11/12	91 7	6/13	46 2	13/17	76 5	35/40	87 5
ormal mobility of subtalar joint	3/24	12 5	2/13	15 4	3/15	20 0	0/16	0	2/17	11 8	22/42	52 4
ormal mobility of talocrural joint	15/24	62 5	10/13	76 9	9/15	60 0	6/16	37 5	8/17	47 1	34/42	81 0
lo residual disability entitling insurance benefits	9/14	64 3	5/9	55 6	7/8	87 5	6/9	66 7	3/7	42 9	20/26	76 9

Tuber joint angle neg or 0° 58.3—31.3 = 27.0 %
Tuber joint angle 1°—10° 61.5—52.9 = 8.6 %
Tuber joint angle >10° 73.3—69.0 = 4.3 %

None of the differences reaches statistical significance In order to be able to evaluate a possible difference between the series, however, these three differences have been summarized so as to construct a standard weighted mean of the differences This calculation has provided the single mean value $\frac{27.0 + 8.6 + 4.3}{3} = 13.3$ % We find that this percentage likewise falls short of statistical significance (95 % confidence interval 13.3± 18.6 %)

A comparative analysis between the two series, designed to estimate the relative frequency of favourable follow up results, (as defined earlier) within the subgroups differentiated by tuber joint angle, provides the figures set down in table 46

This comparison between the two series demonstrates favourable percentage in Widén's series A significance analysis of the 18 percentage differences between the two series however fails to elicit a significant difference for any one of the subgroups differentiated by the tuber joint angle If we calculate the mean of the three percentage differences for each characteristic of the follow up results we arrive at the following tabulation (table 47)

Table 47 Standard weighted percentages and differences of characteristics representing favourable follow up results. Widén's and present series

Characteristic of follow up results	Widén's series	Present series	Difference (per cent)	Standard error of the difference (per cent)	Difference between Widén's and present series for tuber joint angle neg. —0°	Standard error of the difference (per cent)
Excellent+good functional results	64.4	51.1	13.3	9.3	27.0	16.1
Normal gait	72.3	63.9	8.4	8.3	22.9	15.9
No muscular atrophy	79.5	70.1	9.4	8.6	33.8	16.8
Normal mobility of subtalar joint	16.0	21.4	5.4	7.3	12.5	8.5
Normal mobility of talocrural joint	66.5	55.2	11.3	8.3	25.0	10.1
No residual disability entitling insurance benefits	69.1	62.2	6.9	12.1	−2.4	20.3

No significant difference exists From th ... ing the mean error it is evident that the percentage obse ... ference between the two series is uncertain

A comparative analysis of functional ... feasible where Moberg s series is concerned since no foll ... available with the exception of such results as are relevant fro ... ce point of view Both in Moberg s and Widen s series the lapse of ... following injury has been sufficient for a final adjustment to be m d ... all cases which had been entitled to disability benefits In order to compare the three series of insurance cases in this respect the same differentiation by the tuber joint angle as before has been adopted Table 48 shows the distribution of the three series at the time of injury

Table 48 Distribution of insurance cases with respect to tuber joint angle at time of injury Widen s Moberg s and present series

Series	Tuber joint angle at time of injury			Total cases	Data on tuber joint angle missing
	neg –0°	1 –10	> 10°		
Widen (followed up + not followed up)	14+0	9+1	8+0	33+1	2+0
Moberg (not followed up)	10	5	5	22	2
Present series (followed up + not followed up)	9+0	7+1	26+0	42+3	0+2

Widen s series includes one additional case and the present series 3 such cases for which insurance data are available but which for various reasons were not included in the follow up The table shows that the relative frequency of cases with a tuber joint angle exceeding 10 degrees is higher within the present series

A comparison of the three insurance series five years following injury with respect to the degree of disability as rated for insurance purposes within the subgroups differentiated by tuber joint angle, provides the figures set down in table 49 In the present series the follow up period has in many cases been relatively short but as disability benefits are

CHAPTER 10

Evaluation of Results of Different Therapeutic Methods for Fractures of the Calcaneus, in Terms of Insurance Rating

In view of the varying principles of evaluation followed by insurance companies in different countries comparison with insurance series outside the country has little value. Scandinavian sources report the incidence of permanent disability ensuing from fracture of the calcaneus as varying from 8 to 30 % (Olofsson 1940, Kiaer and Antonson 1942, Widén 1954, Rosendahl Jensen 1956 and others). Rosendahl Jensen reported in 1956 on a Danish insurance series including a total of 465 intra-articular fractures of the calcaneus, followed up over a period of at least 8 years. He found permanent disability in 29.7 % of all cases, and twice as much disability in cases treated by secondary arthrodesis as in those treated conservatively or with some form of traction. Olofsson published a study in 1940 which was based on a series derived from the records of the National Insurance Board for the years 1924—1933. His observations included two five-year periods. During the first of these periods the majority of cases had received conservative treatment whereas treatment in the latter period had been predominantly active, mainly in the form of reduction ad modum Böhler. No appreciable difference between the two five-year periods could be established. Olofsson found that half of his calcaneal fractures had healed without residual disability, one fourth had temporary disability and one fourth permanent disability. The average degree of disability was 17 %. Olofsson's failure to classify his fractures and his inclusion of bilateral fractures makes it difficult to compare his series with those of other authors.

Among other Swedish studies of calcaneal fractures evaluated in terms of insurance rating we find Ahlberg's series which includes both cases treated by conservative methods (exercise therapy or plaster fixation) and cases treated by different surgical techniques. Widén's report of insurance cases is based on a series which for the greater part was subjected to

uniform surgical treatment consisting of open reduction Moberg and Erfors report on triple arthrodesis in the treatment of calcaneal fractures was based on too short a period of follow-up to permit any definitive conclusions in terms of insurance rating

The disability rating of Widen s and the present series

It would be useful to include a comparison of the present series in terms of insurance rating with Widen s operated series of cases subjected to uniform surgical treatment In Widen s series so much time had elapsed since injury that the insurance companies have come to a final adjustment of disability claims The data relevant to this comparison are derived from a review of the insurance records of all individuals in the two series who had made application for disability benefits All insurance records were still available for inspection

The following comparison will be concerned with unilateral intra articular fractures of the calcaneus and is designed to determine the frequency and degree of disability the length of hospitalization the period of total occupational disability and the patient s final state of occupational fitness

The two insurance series on which this comparison will be based consists exclusively of men The average age in Widen s insurance series is 46 3 years and in the present series 46 6 years No differentiation of the series by either fracture groups or tuber joint angle has been carried out

In the insurance series which Widen presented in his 1954 study and compared with insurance cases from Ahlberg s series the length of follow up varied between 2 and 8 years All cases included in Widen s insurance series were for the purpose of the present comparison re examined on the basis of their insurance records

Diagram 3 A shows the insurance rating of Widen s series at the time of follow up in 1952 Due to the varying length of follow up the number of cases subjected to insurance rating decreases with each year that passes Diagram 3 B shows the disability rating following final adjustment of all insurance claims It is evident from this figure that the actual frequency of disability in Widen s series is considerably higher than appears from his original presentation (diagram 3 A) The proportion of cases with a final rating of permanent disability is found to be about twice as large In this retrospective analysis we have also taken into account any complaints from patients whose claims for insurance benefits were denied despite residual symptoms Widen s series included two patients who had protested the insurance company s decision, but only one of them suc

Diagram 3 A

Disability rating of Widén s insurance series at follow up in 1952.

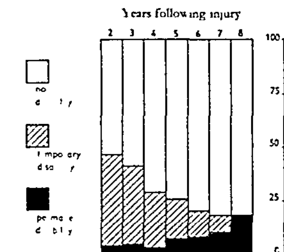
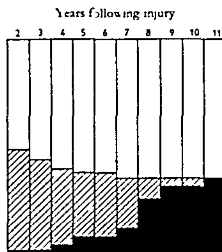


Diagram 3 B

Final adjustment of disability rating in Widén s insurance series



umber of cases																	
o disability	27	29	28	24	13	10	5	26	29	31	32	32	33	33	33	33	33
emporary disability	22	18	10	6	2	1	0	24	21	18	15	15	12	5	2	2	0
ermanent disability	2	2	1	2	1	1	1	1	1	2	4	4	6	13	16	16	18
Total	51	49	39	32	16	12	6	51	51	51	51	51	51	51	51	51	51

ceeded in securing a provisional prolongation of the temporary disability benefits

Widén s insurance series of 51 cases includes 17 patients subjected to some form of treatment other than open reduction As we are interested in evaluating the results for cases subjected to uniform surgical treatment separately these have been collected into a separate series It consists of 34 cases referable to fracture groups VI and VII Their distribution over these fracture groups (and their insurance rating) is illustrated by Diagram 4 A

Diagram 4 B provides a similar presentation of the insurance cases included in the present series and referable to fracture groups VI and VII 45 cases in all Despite the short follow up period of the present series it has been possible to follow the pertinent cases over a period of five years with respect to their insurance rating *)

Diagram 4 A and 4 B show the incidence of temporary and permanent disability in the two insurance series at varying intervals following injury

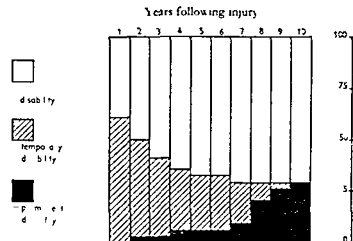
*) Example Case no 58 injured Aug 1958 15 % disability benefit secured until May 1 1964

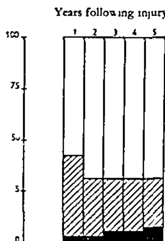
Diagram A

Final adjustment of disability rating for operated patients in Widén s insurance series

Diagram B

Disability rating of present insurance series during first five years after injury





nber of cases															
disability	13	17	20	22	23	23	24	24	24	24	26	31	31	31	31
nporary disability	21	16	13	10	9	9	7	3	1	0	18	13	12	12	11
nanent disability	0	1	1	2	2	2	3	7	9	10	1	1	2	2	3
Total	34	34	34	34	34	34	34	34	34	34	45	45	45	45	45

In Widen s series we find that from 5 years after injury only one of the cases awarded provisional benefits is subsequently transferred to the group without residual disability The other cases with provisonal disability benefits are at some later stage granted a permanent disability pension We further find that in one case final adjustment of the patient s disability rating did not take place until more than 9 years following injury It would seem therefore, that in a series of this type a stationary condition is reached in terms of insurance rating on the average after about 4 years As appears from diagram 4 B the insurance rating of the present series has from 2 years after injury undergone no appreciable changes Those cases which 2 years following injury are in receipt of provisional disability benefits are still collecting them by the end of the 5 year period unless they have already been granted a permanent disability pension by that time For all insurance cases in the present series which at the time of follow up were in receipt of provisional disability benefits functional results were found to be unfavourable (fair or poor) at follow up This evaluation was confirmed on subsequent revision of their disability rating

It is hardly likely that the condition of these patients will improve as far as function is concerned and we may reasonbly assume, therefore, that they will sooner or later become eligible for a permanent disability pension

On the basis of the insurance series compared here, it may be interesting to estimate how the degree of disability changes in relation to the time elapsed since injury Since the number of cases entitled to disability benefits decreases with the years, the average degree of disability for the total insurance series should show a similar decrease This assumption is confirmed by table 50

Table 50 Mean disability in per cent for total insurance series at varying intervals following injury Widén's and present series

Series	Years after injury									
	1	2	3	4	5	6	7	8	9	10
Widén	13.4	6.4	5.1	4.1	3.8	3.7	3.4	3.5	3.5	3.5
Present series	7.9	4.1	4.1	4.1	4.1					

During the first year following injury, the average degree of disability is lower in the present series in comparison with Widén's series This obviously reflects the observation emerging from diagram 4 A and B that the rate of disability during the first years following injury is higher in Widén's series From 2 years after injury the present series shows no further changes and from then on any difference with Widen's series is negligible

Table 51 shows the average degree of disability estimated only for those cases who at varying intervals following injury were still in receipt of insurance benefits

Table 51 Mean disability in per cent for insurance cases entitled to disability benefits at varying intervals following injury Widén's and present series

Series	Years after injury									
	1	2	3	4	5	6	7	8	9	10
Widén	21.7	12.8	12.3	11.7	11.8	11.5	11.7	12.0	12.0	12.0
Present series	18.7	12.9	12.9	12.9	12.9					

It emerges from this table that the degree of disability as estimated in relation to the number of cases receiving insurance benefits has undergone no appreciable changes in either of the series from 2 years after injury onwards We also find that there is no appreciable difference between the 2 series The average degree of disability ranges from 12 to 13 % which is somewhat lower than the 17 % reported by Olofsson One reason for this may be that Olofsson s series includes both bilateral fractures and cases with concomitant injuries Even though no final adjustment of insurance ratings has been effected yet in the present series we may expect the final degree of disability for this series to remain at an average of 13 % In the majority of cases the provisional disability rating remains unchanged or is lowered by the final adjustment

From the sociomedical point of view it may be interesting to establish the length of hospitalization and total occupational disability Table 52 presents a comparison of the two series in these respects

Table 52 Duration of hospitalization and total occupational disability Insurance cases in Widen s and present series

Series	Number of cases	Hospitalization mean time in days and (range)		Total occupational disability mean time in days and (range)	
Widen	34	23 0	(7—88)	210 0	(89—365)
Present series	45	20 5	(0—80)	156 0	(71—390)

In these respects the two series show some variation The average length of hospitalization for the present series may seem relatively high but the patients were intentionally kept in hospital as long as possible to ensure an uninterreputed course of intensive physical therapy during the early post injury period

The degree of disability following fracture of the calcaneus is highly variable dependent on the patient s occupation A patient with a sedentary job such as an office worker is obviously less handicapped by his injury than someone engaged in heavy manual labour as for instance, a construction worker Our findings in the two compared series show that about 90 % of the patients were engaged in heavy labour prior to injury It may be interesting therefore to determine how many of those who are still receiving insurance benefits were forced to turn to lighter work

It is hardly likely that the condition of these patients will improve as far as function is concerned, and we may reasonbly assume, therefore, that they will sooner or later become eligible for a permanent disability pension

On the basis of the insurance series compared here it may be interesting to estimate how the degree of disability changes in relation to the time elapsed since injury Since the number of cases entitled to disability benefits decreases with the years the average degree of disability for the total insurance series should show a similar decrease This assumption is confirmed by table 50

Table 50 Mean disability in per cent for total insurance series at varying intervals following injury Widen s and present series

Series	Years after injury									
	1	2	3	4	5	6	7	8	9	10
Widen	13.4	6.4	5.1	4.1	3.8	3.7	3.4	3.5	3.5	3.5
Present series	7.9	4.1	4.1	4.1	4.1					

During the first year following injury the average degree of disability is lower in the present series in comparison with Widen s series This obviously reflects the observation emerging from diagram 4 A and B that the rate of disability during the first years following injury is higher in Widén s series From 2 years after injury the present series shows no further changes and from then on any difference with Widen s series is negligible

Table 51 shows the average degree of disability estimated only for those cases who at varying intervals following injury were still in receipt of insurance benefits

Table 51 Mean disability in per cent for insurance cases entitled to disability benefits at varying intervals following injury Widén s and present series

Series	Years after injury									
	1	2	3	4	5	6	7	8	9	10
Widén	21.7	12.8	12.3	11.7	11.8	11.5	11.7	12.0	12.0	12.0
Present series	18.7	12.9	12.9	12.9	12.9					

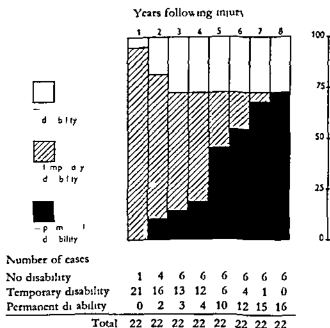
The disability rating of Moberg's series

As already shown in chapter 9 Moberg's cases were treated in an entirely different manner Closed reduction with traction and pinning and later triple arthrodesis were performed The age in this series does not *differ from the two other series However the cases are selected and con*sist of only the severest third of the total number of intra articular fractures admited to hospital during the years in question Only 37 of 98 cases are included and of this number 22 were insurance cases This makes comparison with the other two series difficult and as well no detailed follow up is available However the result from the insurance point of view, can be followed in the cases covered by insurance

A similar presentation as for the other two insurance series has been made for Moberg's insurance cases in diagram 5 which illustrates the incidence of full recovery, temporary disability and permanent disability *at varying intervals following injury We find from this diagram that* during the first year after injury all but one of the patients were in receipt of insurance benefits From 3 years after injury onwards all cases still collecting benefits will continue to do so the provisional benefits being *gradually replaced by permanent disability pensions In one case this was*

Diagram 5

Final adjustment of disability rating in Moberg's series



Number of cases

	1	2	3	4	5	6	7	8
No disability	1	4	6	6	6	6	6	6
Temporary disability	21	16	13	12	6	4	1	0
Permanent disability	0	2	3	4	10	12	15	16
Total	22	22	22	22	22	22	22	22

delayed until 8 years following injury Altogether, 73 % of this series are classified as permanently disabled, which is about twice as high as the rate observed in Widen s series and the expected rate in the present series

Mean disability (in per cent) for the total insurance series following injury will for one to seven years after injury (at varying intervals) drop as follow 50 5 12 7 10 8 10 8 10 6 10 2 10 2

It is also of interest to see that in those difficult cases of Moberg five years after injury the average disability rating is 17 % in his series compared with 11 8 % for Widen s and 12 9 % for the present series

The time in hospital is prolonged in the 22 cases being 57 8 days as an average (range 32 — 95) The total occupational disability is 337 6 days (mean) with a range of 113 — 615 days The working capacity was diminished in only 10 of the 16 patients who received permanent disability payments The remaining 6 patients were able to return to their former occupation

CHAPTER 11

Summary and Conclusion

In an attempt to classify the os calcis fractures according to anatomical principles and in order to elucidate the pathomechanics of these injuries the author has experimentally produced such fractures on post mortem material

Preparations consisting of the lower limb and foot were subjected to a sudden force striking the heel from beneath with varied positions of the foot During the experiments strain gauges registered the force as a function of time

Different types of os calcis fractures were produced resembling those seen clinically The position of the foot at the moment of impact appeared to be the most important factor governing the type of fracture obtained Some of the experiments were followed with a high speed camera which simultaneously registered both the force and the course of the fracture as well as the degree of the compression in the os calcis In the experiments detailed here the force necessary to produce a fracture varied between 600 and 1200 Kp It is possible to explain the fracture mechanism by correlating experimental results with roentgenograms and anatomical findings at dissection

The trauma causing a severe os calcis fracture not only produces the fracture itself but also to a great extent injures the soft tissues Therefore immobilizing the foot for a prolonged period of time makes the restoration of the muscular and circulatory physiology of the extremity more difficult and nullifies the beneficial effect aimed at by attempted reconstruction of the normal anatomy of the injuried bones

The author has analysed unselected clinical material of os calcis fractures that have been treated with early physical therapy This was done in an attempt to evaluate what results this conservative treatment could produce for different types of os calcis fractures and which factors were of importance for the prognosis

The clinical material in the present investigation was taken from some 15 surgical departments in Sweden during the period June 1956 — January 1960 With very few exceptions all cases of os calcis fractures occuring in these departments during this period were treated in a similar way with early mobilization without attempts at reduction The follow up was conducted on an individual personal basis during the latter part of 1959 and early 1960 During this time 121 patients were examined (93 8% of the available total)

The end result of a group of unilateral intra articular os calcis fractures (90 patients) was of special interest The follow up period for the majority of these patients was more than 18 months In this group of unilateral intra articular fractures a good correlation exsisted between the subjective patient complaints after the injury and with the more objectively registered end results of the function of the foot Those patients which were graded as excellent showed a normal gait and a normal or near normal, mobility in the talocrural and subtalar joints

The following factors which were subjected to detailed analysis are of presumable prognostic value the fracture group (according to Widen), type of fracture (according to Palmer), age and sex, the tuber joint angle and the degree of displacement in the posterior articular facet of the os calcis It has been shown that a most significant factor in determining the end results is whether the fracture includes the posterior articular facet or not The degree of displacement of the posterior articular facet is *one* measure of the severity of the fracture In judging the degree of displacement the author has adopted the roentgenological technique set forth by Brodén If the material is divided into three groups according to the degree of displacement of the posterior articular facet (none, moderate, considerable) it is shown that the displacement factor was of greater prognostic significance than the tuber joint angle This latter measurement is the one presently in general use in the grading of the severity of os calcis fractures This present analysis has not shown age sex fracture group and type of fracture to be of any prognostic significance in unilateral intra articular fractures

The end results of the present clinical series were compared to other series one of which was treated with open reduction, the other with triple arthrodesis In this comparison the material of the present series had to be classified according to the magnitude of the tuber joint angle, in order that the differences in degree of severity between the various series could be compared It would have been better and more instructive if this comparison could have been made on the degree of displacement This how-

ever was not possible since the necessary roentgenograms taken at special and significant angles were not available in all the three series

It was possible to compare the end results of the present series to that treated by open reduction It was found that the results were better in the group with severe os calcis fractures (tuber joint angle neg —0) when they were treated by open reduction As for the less severe group (tuber joint angle exceeding 10 degrees) one finds better results in those treated by early physical therapy One explanation for this may be that in the group tuber joint angle exceeding 10 degrees there are fewer cases with considerable displacement and thus in this group the hazards of prolonged immobilization make the result of the operation inferior

The comparison with the series that was treated by early triple arthrodesis was based only on insurance judgements It appeared here that both early physical therapy and open reduction gave better results than an arthrodesis *on the other hand these cases were considered the severest* of those that were admitted to the hospital during that interval

Through the co-operation of the various insurance companies it was possible for the author in the two operatively treated series to follow the insurance judgement in those cases This investigation showed that it sometimes takes up to 11 years before the insurance companies finally have settled an injury of this type It was also found that those cases that had a temporary disability rating 4 — 5 years after the injury would in all probability eventually get a permanent disability rating The average time of working incapacity is lower for those patients with these fractures treated by early physical therapy On the other hand the average degree of disability in the three series compared is about equal The incidence of permanent disability is however greatest in the series treated by triple arthrodesis being twice as common as in the other two series

On the basis of the experimental studies of os calcis fractures combined with review of clinical material treated by early physiotherapy (and comparison with two other differently treated series) the author makes the following recommendations

It is necessary to perform a thorough roentgen examination with special attention to the degree of displacement in the subtalar joint this is essential in order to form an initial specific opinion about the fracture and to further plan the specific treatment Fractures not involving the posterior articular facet ought to be treated with early mobilization without weight bearing thereby reducing both the duration of treatment and the time of hospital stay

As for the intra articular fractures with none or moderate displacement in the posterior joint facet the same treatment is preferable to presently

available operative methods of treatment The early mobilization is best carried out during the first few days in hospital

In the fracture with a more severe displacement an open reduction may give a better result, but in these cases early physiotherapy also can give sufficiently good results to warrant its use instead of the operative treatment

In conclusion the author believes that open reduction in combination with early physiotherapy is probably the treatment of choice in those cases of os calcis fractures with considerable displacement in the posterior articular facet

Acknowledgements

thor is extremely grateful for the aid and advice given unstintingly persons during the conduct of this project and without which this uld not have been possible

vestigation was commenced at the Department of Surgery at the y of Uppsala and was completed at the Orthopaedic Department niversity of Gothenburg It was financially supported by grants Universities of Uppsala and Gothenburg the insurance companies and Skandia in Stockholm and the Medical Association of urg

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CASE REPORTS

Key to the Tabulation of Case Reports*

(Comparative Series)

1 Case number
2 Age in years
3 Sex
4 Fracture group (according to Widen)
5 Fracture type (according to Palmer)
6 Degree of dislocation slight = (+) or considerable = (+ +)
7 Tuber-joint angle of uninjured foot (in degrees)
8 Tuber-joint angle of injured foot initially (in degrees)
9 Tuber-joint angle of injured foot at follow up (in degrees)
10 Defference of tuber joint angle between uninjured foot and injured foot initially (in degrees)
11 Difference of tuber-joint angle between uninjured foot and injured foot at follow up (in degrees)
12 Normal gait and ability to walk on toes
13 Normal gait on flat surface but inability to walk on toes
14 Limping on flat surface and inability to walk on toe
15 Mobility of the subtalar joint difference between uninjured and injured foot (in degrees)
16 Mobility of the talocrural joint difference between uninjured and injured foot (in degrees)
17 Atrophy of the calf muscles (in cm)
18 Valgus deformity
19 Broadening of the heel (in cm)
20 Disability benefit in per cent (insurance cases)
21 Observations time (in months)
22 Hospitalization time (in days)
23 Total loss of working capacity (in days)
24 Functional results

* This table comprises only the unilateral intra articular fractures dealt with in the comparative series Cases 1—17 consist of extra articular fractures discussed in chapter 7 p 47 Cases 116—121 consist of bilateral intra articular fractures discussed in chapter 7 p 61

88	51	♀	VI	1	++	37	20	18	17	19		+		10	5	1 5	+	1 5	15	49	14	238	Poor
89	73	♁	VII	1	+	31	20	16	11	15	+			5	10	1	—	½		53	7	86	Good
90	57	♂	VII	1	+	38	20	18	18	20	+			5	0	1	—	1	0	48	50	150	Exe
91	26	♂	VII	1	+	30	18	8	12	22	+			0	0	0	—	½–1	0	49	8	135	Exe
92	51	♂	VII	2	+	28	–7	–11	35	39	+			15	10	0	—	1 1 5	0	42	20	71	Exe
93	40	♂	VII	1	++	29	18	16	11	13			+	25	5	½	+	½		42	10	264	Poor
94	59	♂	VII	1	+	32	17	12	15	20		+		10	10	2	—	½	15	15	17	109	Fair
95	32	♀	VII	1	++	39	18	18	21	21	+			5	0	0	—	1 5		37	15	182	Fair
96	40	♂	VII	1	++	42	20	20	22	22	+			5	0	1 5	—	½–1	0	37	15	140	Good
97	41	♂	VII	1	++	21	–3	–18	24	39		+		15	10	1 5	+	1 5		34	4	269	Poor
98	27	♂	VII	2	++	38	–6	–8	44	46	+			20	5	0	—	1	0	36	15	104	Fair
100	35	♂	VII	2	++	32	–5	–13	37	45			+	30	20	1 5	+	1 5	15	29	47	346	Poor
101	47	♂	VII	1	++	33	7	0	26	33		+		20	10	1 5	+	1 5	15	26	31	217	Poor
102	57	♂	VII	2	++	38	10	8	28	30	+			10	0	2	—	1 5	0	27	13	185	Good
103	36	♂	VII	2	+	35	10	10	25	25	+			5	0	0	—	½–1		23	19	87	Exe
105	50	♂	VII	1	+	22	2	–3	20	25	+			15	0	½	—	½		22	37	81	Good
106	59	♂	VII	1	+	27	3	0	24	27	+			10	10	½	—	1	0	20	23	162	Good
107	54	♁	VII	1	++	45	9	5	36	40	+			10	0	½	—	1		17	6	125	Exe
108	51	♂	VII	1	++	25	–3	–7	28	32			+	10	15	—	+	1 5	0	18	35	390	Fair
109	42	♂	VII	2	+	36	28	26	8	10	+			5	0	0	—	½		18	6	68	Exe
110	59	♀	VII	2	++	25	–12	–24	37	49			+	20	15	2	+	2		1(	95	413	Poor
111	55	♂	VII	1	++	34	4	2	30	32		+		10	10	2	—	1 5		14	31	182	Fair
112	63	♂	VII	1	++	37	–11	–25	48	(2			+	20	15	½	+	2		14	5	325	Poor
113	69	♁	VII	2	++	25	6	6	19	19	+			15	5	½	—	1		12	14	67	Fair
114	52	♂	VII	1	+	32	16	15	16	17	+			5	0	0	—	½–1	0	14	5	86	Good
115	59	♀	VII	2	+	40	26	26	14	14	+			5	5	0	—	½–1	0	12	32	182	Good

Additional insurance type cases (case no 123 and 124 not followed up)

87	41	♂	VI	2		25	9												0	14	54	237	Good
123	66	♂	VI																20	—	0	273	—
124	55	♂	VI																0	—	10	91	—

Printed in Sweden
ORSTADIUS BOKTRYCKERI AKTIEBOLAG
GÖTEBORG 1954

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM No 7-

FROM THE DEPARTMENT OF ORTHOPAEDIC SURGERY THE NATIONAL MEDICAL CENTER IN KOREA SEOUL, SOUTH KOREA (FORMER HEAD BERNHARD PAUS)

TREATMENT FOR TUBERCULOSIS OF THE SPINE

Anti-tuberculosis Drugs in Conjunction with Radical Operation and Short Hospitalization with no Enforced Recumbency or Immobilization

BY

BERNHARD PAUS

MUNKSGAARD
COPENHAGEN 1964

SCANDINAVIAN UNIVERSITY BOOKS

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Print d in Norway by
AAS & WAHLS BOKTRYKKERI

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Comparison of Results of Treatment

Preface

This investigation was carried out during the period 1958-60 when the author worked as Head of the Department of Orthopaedic Surgery at the National Medical Center in Korea, a hospital located in Seoul and operated jointly by the South Korean and Scandinavian Governments. The first patients were admitted in December 1958. It soon became clear that tuberculosis of bone and joints was a major orthopaedic problem and that there was an apparently unlimited number of patients in this field. The author's appointment was scheduled to terminate in the summer of 1960 and the present investigation was planned accordingly. Subsequently it became possible to extend the investigation so as to include a follow-up study of the patients investigated. This follow-up study was carried out in September-November 1961.

The author wishes to express his sincere gratitude to the institutions which by their assistance made this investigation possible: Norges almenvitenskapelige forskningsrad (The Norwegian Research Council for Science and the Humanities), Medisinaldirektør N. Heitmanns tuberkulosefond (Dr. N. Heitmann's Tuberculosis Fund) and Nasjonalforeningen mot tuberkulosen for folkehelsen (The Norwegian Tuberculosis and Public Health Association). He also wishes to express his gratitude to the Scandinavian board and the administration of the National Medical Center for their support and to Rikshospitalet, Oslo, Norway (The University Hospital) for the granting of leave of absence to undertake his overseas assignment.

It was possible to carry out the present investigation thanks only to the assistance of many Korean and Scandinavian persons in the orthopaedic and other departments. It is impossible to mention all of them by name, but the assistance of Miss Ellen Kilby, Head Nurse of the Department of Orthopaedic Surgery, who was responsible for the nursing care of the patients, may be mentioned together with that of Miss Lee Sun Hee, Social Worker, whose energetic and untiring efforts

in tracing patients for follow up examinations were particularly valuable

The author would also like to thank Professor K Arnesen, M D Oslo Municipal Hospital Professor E Poppe M D , The Norwegian Radium Hospital and Dr A Tuxen M D Oslo Municipal Hospital for Tuberculosis for their help in reviewing and assessing some of the findings Dr T Mork The Norwegian Cancer Registry for statistical advice and Dr T Guthe and Mr J Jackson World Health Organization Geneva for review and editorial assistance

Finally the author would like to mention his particular pleasure in carrying out this investigation since it was in this same field of medicine that his father Nikolai Paus M D , worked for his doctor s thesis

Introduction

The investigation which will be reported in this paper was confined to the problems associated with a certain method of treatment for tuberculosis of the spine Problems of pathogenesis pathology diagnosis etc will not be discussed It is sufficient to recall that the condition may be regarded as a spinal metastasis caused by systemic spread of tubercle bacilli usually to the bodies of the vertebrae

Until the introduction of effective anti tuberculosis drugs treatment for tuberculosis of the spine required enforced recumbency immobilization and hospitalization for several years preferably in specialized hospitals This method will in the following be referred to as orthodox treatment A little more than a decade ago a form of treatment was introduced in which anti tuberculosis drugs were used in conjunction with a direct surgical attack on the lesion Enforced recumbency immobilization and long hospitalization have been required with this method of treatment also although not to the same extent as with orthodox treatment It might well be asked if these procedures could be abandoned in view of experiences in other areas of medicine Thus ambulatory treatment with anti tuberculosis drugs is now sometimes used for pulmonary tuberculosis The reduction in post operative recumbency and hospitalization after resections of the stomach appendicectomies and herniectomies is also indicative although no direct comparison can be made between tuberculosis of the spine and these conditions In South Korea at the time of the present investigation this question was also of practical importance patients with tuberculosis of the spine were numerous while not one single specialized hospital for bone and joint tuberculosis existed in the country and practically none of the patients could afford long hospitalization

It was also felt that a unique opportunity existed to examine what could be achieved by modern medical methods in a country where little had so far been done to combat tuberculosis

Review of Previous Literature on Tuberculosis of the Spine

The literature on the different methods of treatment will be reviewed in the following both in order to assess the results obtained and to determine to what extent the problem posed in the introduction has been discussed by other workers The review is divided into sections according to the type of treatment used (1) orthodox treatment (2) ambulatory treatment with anti tuberculosis drugs (3) radical operation (4) literature on other aspects of tuberculosis of the spine with a particular bearing on the findings in the present investigation and (5) summary of published data

1 Orthodox Treatment

(a) *Treatment*

The orthodox treatment was entirely constitutional in its character and required recumbency immobilization by means of plaster beds body casts or corsets and hospitalization preferably in specialized hospitals for bone and joint tuberculosis There the patient could be exposed to fresh air and sunshine and receive adequate food From 1911 onwards the fusion operation of Hibbs or Albee was carried out in certain cases According to Thomas (1875) the rest required should be enforced uninterrupted and prolonged while Kopnew (1957 p 599) stated that Immobilization must be precise systematic and uninterrupted from beginning to end of the disease bearing in mind that 2 minutes walk renders 48 hours recumbency null and void The average period of time spent in hospital was reported by Alvik (1949) to be thirteen to fourteen months for patients who were discharged only after the completion of treatment but Reinhard (1960a) kept patients in hospital for as long as four to five years

A more extensive survey of the literature on orthodox treatment can be found e g in the monographs of Alvik (1949) and Fellander (1954)

(b) *Results of treatment*

Clinical findings. On the basis of the total number of patients treated, 29.1–44.0 per cent were found to have full working capacity, while on the basis of the follow-up of surviving patients the figures were 60.7–69.5 per cent. The figures for patients with partial or full working capacity on the same basis were 36.5–73.0 per cent and 80.0–87.3 per cent respectively (ALVIK 1949, FELLANDER 1954, KONDO & YAMADA 1957, BAKALIM 1960 and REINHARD 1960). The period of observation varied from twelve months to twenty-four years.

Subjective complaints in the form of pain, tiredness, weakness or stiffness in the back were reported in 14.7–73.4 per cent of the cases (ALVIK 1949, KONDO & YAMADA 1957 and BAKALIM 1960).

Complete recovery from paraplegia in 10 out of 23 cases was reported by ALVIK (1949), in 80 out of 143 cases by GRIFFITHS, SEDDON & ROAF (1956), and in 18 out of 31 children by KAPLAN (1959).

Radiological findings. Healing was reported in 35.0–55.0 per cent and fusion in 48.09–52.5 per cent of these cases (ALVIK 1949, FELLANDER 1954, HALLOCK & JONES 1954 and BAKALIM 1960).

Interval between discharge or operation and resumption of work. An interval between discharge and resumption of work of up to six months was reported by ALVIK (1949) in 24.46 per cent, and up to one year in 58.16 per cent of 184 patients who were subsequently able to work and where this interval was known. BAKALIM (1960) found that the interval between the fusion operation and the resumption of work was less than one year in 101, and less than two years in 124 cases out of a total of 208 on whom the operation was performed, i.e. a proportion of about 50.0 and 60.0 per cent respectively.

Kyphosis could develop or increase while the patient was being treated in a plaster bed, and the fusion operation had little or no effect in preventing its development, at least with dorsal lesions (ALVIK 1949, HALLOCK & JONES 1954, BAKALIM 1960, ROAF 1960 and INGELRANS 1961). Moderate or very large kyphosis was reported by BIERRING (1934) in eight out of 17 children and 10 out of 59 adults, most of whom were followed up eight to eleven and a half years after the Albee fusion operation. ALVIK (1949) found the same degree of kyphosis in 20.51 per cent of 273 patients observed for at least two years, while KAPLAN (1959) found severe and gross kyphosis in 45 out of 96 children where four or more vertebral bodies were affected. HALLOCK & JONES (1954) found an increase in radiological kyphosis of 10 or more in 31 out of 79 lesions in patients followed up five to twenty-two years after fusion

Review of Previous Literature on Tuberculosis of the Spine

The literature on the different methods of treatment will be reviewed in the following both in order to assess the results obtained and to determine to what extent the problem posed in the introduction has been discussed by other workers The review is divided into sections according to the type of treatment used (1) orthodox treatment (2) ambulatory treatment with anti tuberculosis drugs (3) radical operation (4) literature on other aspects of tuberculosis of the spine with a particular bearing on the findings in the present investigation and (5) summary of published data

I Orthodox Treatment

(a) *Treatment*

The orthodox treatment was entirely constitutional in its character and required recumbency immobilization by means of plaster beds body casts or corsets and hospitalization preferably in specialized hospitals for bone and joint tuberculosis There the patient could be exposed to fresh air and sunshine and receive adequate food From 1911 onwards the fusion operation of HIBBS or ALBEE was carried out in certain cases According to THOMAS (1875), the rest required should be enforced uninterrupted and prolonged while KORNEW (1957, p 599) stated that Immobilization must be precise systematic and uninterrupted from beginning to end of the disease bearing in mind that 2 minutes walk renders 48 hours recumbency null and void The average period of time spent in hospital was reported by ALVIK (1949) to be thirteen to fourteen months for patients who were discharged only after the completion of treatment but REINHARD (1960a) kept patients in hospital for as long as four to five years

A more extensive survey of the literature on orthodox treatment can be found e g in the monographs of ALVIK (1949) and FELLANDER (1954)

and fusion in 153 patients (74.0 per cent). The interval between the beginning of treatment and the resumption of work was less than twelve months in 109 cases (59.0 per cent). Recovery from paraplegia was seen in 26 out of 28 cases in which surgery was not used and in 25 out of 28 cases after costectomy. The kyphosis increased by 11° or more in 77 cases—as assessed from their histogram—out of the total of 207 patients (37.2 per cent).

3. Radical Operation

The term "radical operation" has often been used to indicate a direct surgical attack on the spinal lesion including evacuation of abscesses and curettage of the lesion. The term is somewhat misleading, since eradication, meaning complete elimination of all the diseased material, cannot be effected (Fig. 1). However, because of the wide acceptance of this term, it will nevertheless be used in the following text.

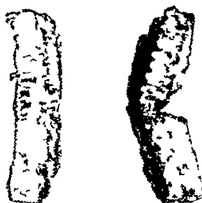


Figure 1. *Specimen of spine after radical operation.*

A 5-year-old boy was admitted to another department because of some other disease but died shortly after admission. His tuberculosis of the spine was operated in the usual way but post mortem, and this specimen was then removed. Macroscopic granulation tissue and bone sand both in small amounts and remnants of a disc were found in the specimen at the site of the lesion.

The operation was reported by Treves (1884), Krause (1889), Ménard (1900), Müller (1906), Ito, Tsuchiya & Asami (1934) and Casuto (1951). There were many good isolated results. Complications were, however, frequent and serious, and the operation was advised against by Schmieden (1930). The teaching outlook was aptly expressed by Calot (1930, p. 223) as follows: "The surgeon who, so far as tuberculosis is concerned, swears to remove the evil from the very root will only find one result waiting him—the death of his patient." After the anti-tuberculosis drugs became available, radical operation was once more introduced in a combined method of treatment.

(a) *History*

WILKINSON (1949) HALD (1950) ORELL (1951 1951 a and b) KASTERT (1951 1951 a) KONDO & YAMADA (1951) were the first to report the treatment with anti tuberculosis drugs in conjunction with direct surgical attack on the spinal lesion For detailed information on the history of this combined method of treatment the reader is referred to EHRLACHER (1952) and STEVENSON (1957)

(b) *Indications and contra indications*

A variety of opinions has been expressed by various authors in regard to the indications for the use of this combined method of treatment Thus HALD (1952 p 88) advocated that it should be employed more often than has been done so far FELLANDER (1954) KASTERT (1957) BOULVIN (1960) and DEBEYRE (1961) performed the operation with little regard to factors such as the age of the patient and the stage or extent of the disease while STEVENSON (1957) and REINHARD (1960 a) evaluated each case individually HODGSON & STOCK (1960 a) operated on selected cases of florid disease GUICHAUX (1960) operated only after first having tried conservative treatment, while DAUBENSPECK & RAUSCH (1955) and GUERIN (1961) found that the indications were very limited BAKALIM & LANGENSKIÖLD (1960) found the operation practicable in only 10 0 per cent of their cases WEBER BERLEMONT & HIRTZMANN (1961) found the operation indicated only for diagnostic purposes in uncertain cases and a most unfavourable view was expressed by PERKINS (1961 p 119) Excision is not practical when the area is unapproachable as in disease of the spine

In children WILKINSON (1955) MUKOPADHAYA (1956) and STEVENSON (1957 a) found the indications to be wider than in adults and STRAFINOVA & MALAWSKI (1959) operated on all cases but REINHARD (1960 a) was reserved in his opinions FERRAND (1961) operated only after having first tried prolonged medical treatment while DELAHAYE JACOB & TEEPS (1961) felt that the operation was unnecessary in young children

The divergence in the views expressed at a symposium in Paris, 1961 was summarized by DEBEYRE (1961 b) to the effect that some surgeons operated in every case but others were content to use drugs alone

Differences of opinion exist also as to the contra indications Thus MAY (1954) HALL & ADAMSON (1956) MUKOPADHAYA (1956) KONDO & YAMADA (1957) and RISKO & NOVOSZEL (1963) would not operate in the early stage of the disease while DAUBENSPECK & RAUSCH (1955) BAKALIM & LANGENSKIÖLD (1960) and HODGSON STOCK FANG & ONG

(1960) hesitated to operate in advanced extensive cases KASTERT (1957) BAKALIM & LANGENSKIOLD (1960) HODGSON & STOCK (1960) REINHARD (1960 a) and MARCONI BOMBELLI & MIRABELLA (1960) regarded pulmonary tuberculosis as a possible or complete contraindication for the operation

(c) *Treatment*

The *medication* used was isoniazid (INH) para aminosalicylic acid (PAS) and streptomycin (SM) either all together or in various two drug combinations The period of pre operative medication varied from eight days (KASTERT 1957 and BOULVIN 1960) to three months (WILKINSON 1959 KATAYAMA 1961 and DEBEYRE 1961) Such pre operative medication was sometimes waived by FELLANDER (1957) and DEBEYRE (1961) The period of post operative medication varied from three months (FELLANDER 1957) to eighteen to twenty four months (BAKALIM & LANGENSKIOLD 1960 and HODGSON & STOCK 1960 a) At the Paris symposium in 1961 the conclusion was reached by DEBEYRE (1961 b) that the usual period of medication was twelve to eighteen months

Operation All authors agree on the main principle to open the abscess and remove the diseased material of the spinal lesion but they have different and sometimes controversial opinions on details of technique and in regard to additional procedures

The importance of additional constitutional treatment was emphasized by WILKINSON (1949 61) more than by anyone else Flushing of the wound with saline solution and deposition of SM before closure was used by ORELL (1951 56) a posterior fusion operation was usually done but not always or preferably an anterior intercorporeal fusion by the use of bone grafts in the bone cavity Anterior fusion operation was routinely carried out by HODGSON & STOCK (1956 1960) Local post operative instillation of anti tuberculosis drugs through a tube for six weeks was emphatically advocated by KASTERT (1951 60) Packing the wound with gauze for twelve to fourteen days and letting it close by secondary healing was the procedure used by DEROY & FISHER (1952) Filling of the bone cavity with a mass of plaster and SM was used by FRUND (1951)

A posterior fusion operation was used by GRUCA (1957) RISKÓ & NOVOSZEL (1959 1963) and DELAHAYE *et al* (1961) Either anterior or posterior fusion was used by SERAFINOVA & MALAWSKI (1959) The bone cavity was packed with grafts in special cases by KONDO & YAMADA (1951 61) EHRLACHER (1954 1956) HALD (1955) and MUKO

PADHAYA (1956). Some of these authors found this appropriate in cases with small cavities only, while others used the procedure only in cases with large cavities. The cavity was filled with grafts more routinely by CAUCHOIX, MECHELANY, TERSEN, MOREL & COTREL (1961). The destroyed vertebral body was replaced by a bone block from the upper part of the tibia or by a complete vertebral body from a bone bank by FEHLANDT (1954) and FERRAND & BARSOTTI (1961). Panarthrodesis with both anterior and posterior fusion operation was advocated by HALL & ADAMSON (1956), BAKALIM & LANGENSKIÖLD (1960), CAUCHOIX *et al.* (1961) and GRUCA & SERAFIN (1961).

Packing the lesion with bone grafts and posterior fusion operation were, on the other hand, considered unnecessary or undesirable by DEPOX & FISHER (1952), FELLANDER (1957), KASTERT (1957 a and b), BOULVIN (1960), SCHEPEL (1960) and DEBEYRE (1961).

The period of post-operative local instillation of drugs was shortened by SCHEPEL (1960) and DEBEYRE (1961) to two and three weeks respectively. MUKOPADHAYA (1956) and BOULVIN (1960) used daily instillations instead of continuous drip for three weeks and thirty-five to sixty days respectively.

The operative approach differed with the surgeon and with the location of the lesion. It is mentioned that MACRAE (1957) used a bilateral costotransversectomy, and REINHARD (1960 a) operated on lesions in L 1-4 in two stages, first emptying the lesion from behind and later removing abscesses from the front.

The method of dealing with abscesses varied from the complete removal of the abscess wall to mere opening and evacuation. The removal of diseased material was usually completed by curettage of the spinal lesion. However, in children KARLÉN (1959) removed only the necrotic material which presented itself spontaneously and avoided curettage.

Post-operative recumbency and hospitalization. There has been no typical duration of the post-operative recumbency. DEPOX & FISHER (1961) allowed their patients to get up a few days after operation. Periods of two months have been reported, FELLANDER (1954) and KATAYAMA (1961), as well as eight to twelve months, REINHARD (1960 a). Most authors reported that postoperative recumbency lasted from three to eight months.

Hospitalization lasted from four to six months in most instances but here again there have been wide variations. Thus MUKOPADHAYA (1956) was forced by circumstances to reduce hospitalization to six to seven weeks. FELLANDER (1957) reported that hospitalization was less

than three months in 53.0 per cent of his cases On the other hand a period of eighteen months or not much less than after orthodox treatment and fusion operation was reported by BRUNNER (1954) REINHARD (1960 a) and DEBEYRE (1961 c)

Immobilization by the use of plaster beds body casts and corsets has been generally effected and over a longer period of time than that spent in the recumbent position or in hospital Thus MUKOPADHAYA (1956) immobilized his patients for six to eight months but hospitalized them for only six to seven weeks while REINHARD (1960 a) immobilized patients for three years but hospitalized them for eighteen months On the other hand FELLANDER (1954) abandoned the use of plaster beds for patients who had previously undergone the fusion operation KATAYAMA (1961) gradually gave up their use but continued to use corsets for six months after the patient had got up DEBEYRE (1961 c) gave up almost completely the use of both plaster beds and corsets and DEROY & FISHER (1952 1961) gradually stopped all use of immobilization

(d) *Results of treatment*

Clinical findings Complete restoration of working capacity was reported by various authors in 73.3–95.7 per cent of patients and complete and partial working capacity in 68.0–95.7 per cent (Table 1) BOULVIN (1960) followed up 65 patients out of a group of 103 and found both clinical and radiological healing in 61 of them

Slight complaints were reported by FELLANDER (1954) in 11 out of 100 patients 11.0 per cent by BAKALIM & LANGENSKIOLD (1960) in at least eight out of 18 patients and by KONDO (1961) in 29 out of 90 patients 32.3 per cent

Recovery from paraplegia was reported by KASTERT (1957) in 11 out of 19 cases by HODGSON & STOCK (1960) in 26 out of 35 by CAUCHOIX *et al* (1961) in 12 out of 22 and by PISKÓ & NOVOSZEL (1963) in 10 out of 10 cases

Radiological findings Healing was reported by various authors in 52.0–94.0 per cent of the cases (Table 2) and bony fusion was found in 38.0–94.0 per cent when complete and incomplete fusion were considered together MUKOPADHAYA (1956) was apparently unable to follow up all his patients but, of 56 thus followed all were found to have healed KASTERT (1957) reported fusion in 96.2 per cent of about 1 000 patients but he failed to differentiate between bony and fibrotic fusion DEROY & FISHER (1961) in just over 100 patients who had been observed for as long as ten to twelve years found that these

— Dr Bernhard Paus

TABLE 1 *Working capacity after treatment with anti-tuberculosis drugs in conjunction with radical operation for tuberculosis of the spine*

Authors	Patients	Observation period	Working capacity			
			Complete		Complete and partial	
	Number	Years	Number	Per cent	Number	Per cent
Fellander (1954)	100	1–4	62	62.0	68	68.0
Serafinova & Malawski (1959)	389	–	–	–	–	80.0
Bakalim & Langenskiold (1960)	18	2–10	12	–	13	–
Cauchoix (1961)	204	–	180	88.4	–	–
Debeyre & Deprion (1961)	263	1–7		–	–	94.0
Kastert (1961)	app 1500			–	–	90.0
Kondo (1961)	90	1–9	48	53.3	76	84.6
Wilkinson (1961)	138	10	132	95.7	–	≥ 95.–
Fako & Novoszel (1963)	105	–	–	–	89	84.7

TABLE 2 *Radiological findings after treatment with anti-tuberculosis drugs in conjunction with radical operation for tuberculosis of the spine*

Authors	Patients or lesions	Observation period	Radiological findings	
			Healing	Fusion
	Number	Years	Per cent	Per cent
Fellander (1954)	100	1–4	52.0	42.0
Wilkinson (1957)	84	–	–	53.6
Wilkinson (1959)	130	1–10	92.3	–
Fako & Novoszel (1955)	103	2–5	–	57.0
Bakalim & Langenskiold (1960)	18	2–10	–	55.0
Hodgson & Stock (1960)	100	2–4	–	94.0*
Hodgson (1961)	300	–	–	78.7*
Cauchoix *et al.* (1961)	204	–	–	84.5
Debeyre (1961)	100	4–7	94.0	38.0
Fako & Novoszel (1963)	10	–	–	60.0

* The difference [illegible] the findings is due to the extension of the operation to [illegible] al [illegible] anterior fusion, *Hodgson* (1963)

individuals remain perfectly stable and almost invariably will go on to spontaneous fusion

Interval between operation and resumption of work The following intervals have been given by FELLANDER (1954)

Interval (months)	*Number of patients*	*Cumulative total*
2–6	13	13
6–9	19	32
9–12	11	43
12–24	19	62
More than 24	2	64

WILKINSON (1957) reported a period of twelve to fourteen months and CAUCHOIX *et al* (1961) a period of sixteen months

Kyphosis was mentioned by WILKINSON (1953) who performed an anterior fusion operation on two children because of progressive deformity the deformity continued to increase in one of these children CAUCHOIX *et al* (1961) found that kyphosis increased in 25 0 per cent of their patients They concluded that anterior fusion operation could prevent kyphosis only in early cases or in old cases which either were stable or had been stabilized by means of posterior fusion the operation for which should preferably be carried out three months prior to that for anterior fusion Unfortunately they gave no information on the age of their patients PISKÓ & NOVOSZEL (1963) found that anterior fusion operation did not prevent an increase in kyphosis when three or four or more vertebrae had been destroyed

Mortality The operative mortality reported by various authors was 0 0–9 9 per cent (FELLANDER 1954 KASTERT 1957 WILKINSON 1959 BOULVIN 1960 HODGSON *et al* 1960 and REINHARD 1960 a)

4 OTHER ASPECTS OF TUBERCULOSIS OF THE SPINE

The papers on other aspects of tuberculosis of the spine which are reviewed here will be restricted to a few which have some relevance to the present investigation

The correct *diagnosis* of tuberculosis of the spine is of obvious importance in any study of treatment methods It is therefore of interest that the same clinical and radiological features may be encountered in chronic pyogenic spondylitis (ALVIK 1951) and in ot

Objectives and Plan of the Investigation

The foregoing review of the literature shows that no report was found on a planned study of the problem raised in the introduction namely

(i) *can enforced recumbency immobilization and long hospitalization preferably in a specialized hospital be omitted in the treatment for tuberculosis of the spine by anti tuberculosis drugs in conjunction with radical operation?*

The main objective of the present investigation was therefore to examine whether such a treatment was practicable and justified at least in a country with conditions like those prevailing in South Korea at the time If the findings should be in the affirmative a further objective would be to study

(ii) *what effect on prognosis could be ascribed to the various relevant factors?*

The investigation was planned to include studies in which a group of patients would be treated with anti tuberculosis drugs in conjunction with radical operation this group is referred to in the subsequent text as group A The drugs would be restricted to INH and PAS as long as the patients remained outside the hospital SM would be added only while the patients were in the hospital The purpose of this procedure was to ensure that the treatment would be as uniform as possible The daily doses used were standardized in proportion to body weight the duration of the pre operative medication period would depend on uncontrollable factors including the varying waiting time before admission to the hospital and possible medication before the first consultation at the hospital This would however permit a study of the possible effect on prognosis of the variation of this medication period The post operative medication period was planned to last from twelve to eighteen months

The operation was to be carried out as soon as possible after the diagnosis had been made and would aim at as complete elimination of the diseased material as possible. SM would be left in the wound which would be closed primarily. Bone grafting in the cavity, fusion operation and local post operative instillation of anti tuberculosis drugs would not be used.

Recumbency would not be enforced or even encouraged but patients would be allowed to get up as soon and as much as they liked; immobilization would be replaced by active exercises. The treatment would be carried out in a general hospital; hospitalization was planned to last from four to six weeks. This was believed to permit the completion of all the necessary pre operative examinations and a post operative hospital stay similar to that for other types of surgery of the same magnitude.

The effect obtained by this treatment would be compared with the results obtained by the usual methods of treatment.

The results might be due to a combined effect of the drugs and the radical operation, but might also be due to the anti tuberculosis drugs alone, or the operation, or even to a spontaneous natural course of the disease. In order to examine the effect of the anti tuberculosis drugs alone, it was planned to treat a second group of patients with the drugs but without operation. This group is referred to as group B in the subsequent text. The treatment in this group should otherwise be as identical as possible to the treatment in group A. Since it was originally considered that the investigation would have to be discontinued in July 1960, the treatment given to the patients in group B had, however, to be limited to only one year. For ethical and human reasons control groups (i) undergoing radical operation without addition of anti tuberculosis drugs and (ii) receiving no treatment could not be included in the plan.

In order to examine the effect of factors other than the operation on prognosis, it had been preferable to establish criteria for certain subgroups of group A and admit patients for treatment only when they satisfied these criteria. Again, for human reasons this was not possible and it was decided to leave to chance the types of patients to be represented in the material under investigation. The plan for allotting patients to group A or group B is discussed on pages 27-28.

Practical Considerations

Before the studies could be started certain practical questions had to be considered Thus it was necessary to consider whether the number of persons in the population suffering from tuberculosis of the spine was sufficiently large for the required number of patients to enter the hospital within the period available for the investigation It was also necessary to consider whether the hospital was sufficiently well equipped and its regulations such as to permit the carrying out of the necessary examinations and treatment of the required number of patients — again within the period available Finally it had to be considered whether it would be possible to regulate and control the treatment so that it could be carried out according to plan

(a) *Number of patients in the population*

No exact data are available in regard to the number of individuals in South Korea suffering from tuberculosis of the spine However mass tuberculin testing carried out in 1957 58 and mass radiography of tuberculin positive individuals in Seoul and the surrounding districts from which most of the patients would come illustrate the nature and extent of tuberculosis infection in general (KOREAN MINISTRY OF HEALTH AND SOCIAL AFFAIRS 1957 1958 HAN 1959)

Age (years)	*Proportion giving positive result in the tuberculin test (per cent)*
5	28 7–47 5
10	63 9–67 7
15	91 3

Pulmonary tuberculosis was found in 4 2–5 8 per cent

As the population amounted to more than five million people it [illegible] there were probably about 250 000 persons

suffering from pulmonary tuberculosis in the area which the hospital would mainly serve This prevalence was so high that it was believed that the number of persons suffering from tuberculosis of the spine was large enough to ensure the availability of study material required for the plan of investigation and that sufficient patients would consult the hospital within the period available

(b) *National Medical Center in Korea*

This is a general hospital constructed in 1957–58 and operated jointly by the Scandinavian and South Korean Governments for the main purpose of providing postgraduate training for Korean doctors and nurses Its equipment is that of a Scandinavian university hospital At the time of this investigation it had departments for 18 specialities including the following of particular interest for the investigation orthopaedic surgery radiology biochemistry microbiology pathology anaesthesiology and physiotherapy Every clinical department had an out patient clinic and a ward section Each department had a Scandinavian specialist as head of department possibly with a Scandinavian assistant and several Korean doctors

Patients wishing to be admitted to the hospital had to file an application containing particulars of sex age nature of complaint etc The first medical examinations were undertaken at the out patient clinic after which the Scandinavian head of the department decided as to admission to the ward After discharge from the hospital the patients were instructed to return to the out patient clinic for control examinations

According to the hospital regulations at least 75 0 per cent of the patients were treated free of charge They belonged to the poorest sections of the population In practice more than 90 0 per cent of the patients with tuberculosis of the spine belonged to this category Cases of particular interest from the medical point of view could also be treated free of charge The flexibility of the regulations made it possible to examine and treat patients without regard to cost Medicaments for use in ambulatory treatment were also given free of charge

From these considerations it will be noted that the hospital had the necessary equipment and its regulations were such as to enable the necessary examinations to be carried out and the proposed treatment to be given On the other hand the number of patients that could be admitted was limited by the fact that the orthopaedic ward had only 30 beds and was expected to receive orthopaedic patients of all kinds

(c) *Regulation and control of treatment*

Since the plan was to give patients a great deal of freedom, control was required only of the post operative hospitalization period and to ensure that anti tuberculosis drugs were taken according to instructions Control of the post operative hospitalization period could be effected by planning the discharge e g a week in advance and making the necessary arrangements To ensure that the drugs were actually taken a nurse could watch their actual ingestion as long as the patients were in the hospital but this could not be supervised in ambulatory patients it is obvious that the patients might sometimes sell the free drugs to obtain money It is also normal for patients to tire of taking drugs over long periods or for a patient who feels completely fit to forget his prescribed drug regimen In the conditions of life in South Korea it was thought most effective to give patients a supply of drugs for only two to three months at a time and to instruct them to return for new supplies and for a control examination which included a test for PAS in the urine

Procedures

(a) *Construction of patient groups*

Inclusion of patients in the studies Group A was intended to include unselected patients For different reasons some selection was nevertheless inevitable However on the whole it was of such a nature that it is believed not to have had any important effect on the results The main selection factors are discussed below

As mentioned on page 25 patients filed an application for examination at the out patient clinic As a rule all applicants were given an appointment but there were two exceptions (i) individuals living more than six to eight hours travelling distance from the hospital were not admitted since it was thought that they would probably have difficulty in attending regularly for subsequent control examinations (ii) when too many individuals applied patients with paraplegia were favoured but the procedure was mostly that from the pile of applications as many patients as could be admitted to the hospital were drawn by a blind procedure

Division of patients into groups At the out patient clinic a preliminary interpretation of the radiographs of the spine was made Patients were divided into those with one to three vertebrae affected every second one of these was consistently included in groups A and B alternately All those with four or more vertebrae affected were included in group A Thus with the exception of the latter patients were assigned to the two groups in the order in which they finished their first examination at the out patient clinic without any selection At certain times it was impossible to admit all patients to the ward because of the limited capacity of the orthopaedic ward because it was required to treat orthopaedic cases of all kinds and owing to the fact that the main purpose of the hospital was teaching During such periods which lasted for as long as two weeks at a time patients were

advised to go elsewhere for treatment i e no selection of cases was then made and no patient was included in either group

About two months were required from the time the first patient was admitted to the beginning of the investigation All patients with tuberculosis of the spine admitted during this period were subsequently included in group A while the establishment of group B only started after these first two months Since it was proposed to treat these patients for a period of one year, and since the investigation was to be completed by July 1960 the inclusion of patients in this group was terminated in June July 1959 Because of the limited time thus available for the establishment of group B it ultimately included only 45 patients as contrasted to 100 patients in group A As already mentioned group B was intended to be constructed only of patients with one to three vertebrae affected but if subsequent more exact study showed a more extensive lesion than that assessed during the preliminary interpretation of the radiographs the patients were never theless retained in the group Group B also contained a few patients who had originally been allotted to group A but who after a period of ambulatory treatment had decided that they did not wish to undergo operation Finally it contained two children who had been admitted to the paediatric department for other reasons and who had been treated and examined by that department for several months before they were ultimately transferred to the orthopaedic department

After the construction of groups A and B had been completed a further group of eight patients were operated upon without the addi tion of anti tuberculosis drugs

(b) *Examinations and diagnosis*

The examinations included clinical radiological biochemical microbiological and histological examinations

Clinical examinations At the patient s first visit to the out patient clinic the clinical examination was carried out by a Korean doctor on the staff of the department He then demonstrated the patient to the author (in 85 0–90 0 per cent of the cases) or to his Scandinavian assistant Following admission all patients were examined personally by the author The control examinations were carried out by a Korean doctor sometimes alone and sometimes with the author or his Scandi navian assistant In a follow up study in the spring of 1960 the clinical examination of all the patients seen was carried out by the author in [illegible] study in the autumn of 1961 the author examined 136 out [illegible] seen the remainder being examined by other

doctors from the hospital In all these examinations one of the Korean orthopaedic surgeons or the author's Korean secretary who spoke English fluently was available as interpreter

Radiological examinations were carried out in the Department of Radiology of the hospital[1] A radiological examination formed part of the initial and final examinations of all patients and of most of the control examinations Plain films were taken of the antero posterior and lateral views and for most patients tomograms were taken once or several times with a distance of ½–1 cm in frontal and sagittal planes The radiographs were examined at the time by the Department of Radiology When the present report was prepared however all radiographs of the spine were reviewed by the author in discussions with a leading radiologist[2]

Radiographs of the lungs were made of all patients at the initial examination at occasional control examinations and during the final follow up examination The radiographs of patients with pathological findings were reviewed and the development which had occurred was assessed by a leading specialist in chest diseases[3]

Biochemical examinations were carried out at the Department of Biochemistry of the hospital[4] The patients urine was tested on all visits to the out patient clinic on admission to the ward and possibly also during hospitalization to determine pH specific gravity and content of protein pus and sugar In addition the erythrocyte sedimentation rate (ESR) was measured haemoglobin (Hgb) was determined and the Mantoux tuberculin test was carried out the blood group was determined after admission The determination of PAS in the urine by the ferric chloride method was undertaken by the staff of the Department of Orthopaedic Surgery

Microbiological examinations were carried out at the Department of Microbiology of the hospital[5] Examinations for tubercle bacilli were made in material removed at operation in pus obtained by aspiration or from draining sinuses in the urine and sometimes in the sputum Examinations for drug resistance of tubercle bacilli could be

[1] Dr B Lilja M D Halmstad Sweden Dr N Lauge Hansen M D Randers Denmark and Dr K Laverud Oslo Norway were successively in charge of this department during the investigation period

[2] Professor E Poppe M D Oslo Norway

[3] Dr A Tuxen M D Oslo Norway while he was in charge of the Department of Chest Diseases at the hospital in Seoul 1962

[4] Professor S L Sveinsson M D Oslo Norway and Dr B Rosenlund Oslo Norway were successively in charge of this department during the investigation period

[5] Dr K Kalbak M D Copenhagen Denmark was in charge of this department during the whole of the investigation period

carried out only from the spring of 1960 onwards. Typing of tubercle bacilli could not be done at the hospital. In certain cases the examination for bacilli in the urine was undertaken only after the patient had begun to receive anti tuberculosis drugs.

Histological examinations were carried out at the Department of Pathology of the hospital.[1] When the investigation was completed all the sections made were reviewed by a leading histopathologist.[2] (The expression tuberculous granulation tissue has been used in this report for the sake of brevity where the histological features found were similar to those found in tuberculosis although this finding in itself is no definite proof of tuberculosis.)

The *diagnosis* was based on the case history and on the results of the clinical and radiological examinations. It was verified or supported by the microbiological and histological findings in 81 cases out of the total of 100 in group A and in 13 cases out of the total of 45 in group B. During the investigation period a pre operative diagnosis of tuberculosis was amended as a result of the operative and the laboratory findings in one case to that of osteoid osteoma in a second case to haemangioma and in three cases to staphylococcal osteomyelitis these five cases were not included in the investigation.

(c) *Treatment*

Medication included anti tuberculosis drugs in the following doses

Drug	*Dose*
INH	5–6 mg per kg body weight per day in adults somewhat more for children
PAS	0 2–0 3 g per kg body weight per day
SM	1 g per day in adults in small children $^1/_2$–$^3/_4$ g per day or 1 g every other day

In accordance with the plan of the investigation the length of the pre operative medication period was left to chance. The post operative period varied as will be discussed later. Patients were given multi vitamin tablets as a matter of routine a few were also given iron tablets.

Operation Patients were admitted for surgery as soon as this was permitted by the limited ward capacity. The operation was performed immediately on completion of all necessary examinations unless some

[1] Professor K Arnesen M D Oslo Norway and Dr J Ringsted M D Copenhagen Denmark were successively in charge of this department during the investigation period

[2] Professor K Arnesen M D Oslo Norway

intercurrent disease made postponement essential The only exceptions to this rule were the first five patients who were kept in hospital for some weeks before operation Pulmonary tuberculosis was not regarded as a contra indication for operation nor was anaemia

The operative approaches were uniformly as follows

Vertebrae affected	*Approach*
Cervical and dorsal 1-3	Cervical incision along the medial border of the sterno cleido mastoideus muscle
Dorsal 4-12	Costotransversectomy or simple rib resection of one to three ribs the latter was often sufficient in children
Lumbar 1-4	Transversectomy or kidney incision
Lumbar 5-Sacrum	Transperitoneal approach

The bony lesion was exposed through the abscess where this was present It was necessary in some cases to chisel a window through grossly normal bone in order to reach a lesion in the interior of a vertebra diagnosed by radiography A thorough curettage was carried out with removal of affected bone and disc tissue as completely as possible While this was being done an abscess on the other side of the spine would as a rule be entered The dura was often exposed and always in cases with paraplegia With this technique and with extensive lesions inspection of the whole of the lesion was not possible the inspection had partly to be carried out by palpation with the index finger or even by means of the curette

The abscess wall and the sinus tract where this was present were curetted but were removed only to the extent that such removal could be easily effected

Suction was used throughout the operation in an attempt to reduce the spread of pus and diseased material in the wound At the end of the operation the wound was flushed vigorously with large amounts of saline solution large tubes being used to reach the bottom of deep pockets The operation was completed with a final flush with hydrogen peroxide 2 g or more of powdered SM were deposited in the cavity and the wound was closed by primary suture In operations in which the approach was by kidney incision a drain was left in for two to three days Bone grafts and post operative local instillation of anti tuberculosis drugs were never used

Operations on double lesions were carried out in two stages Cases with a large abscess on both sides were operated on bilaterally in one or two stages The second operation as well as operations for complicating tuberculosis of the hip knee sacro iliac joint or pubic bone were carried out fourteen to twenty five days after the first operation

Radiological examination of the site was usually carried out during the operation (Fig 2) A post operative radiological examination was carried out after costotransversectomy or rib resection to determine whether pneumothorax was present

The operation was performed under general anaesthesia with intubation and with blood transfusion



Figure 2 *Radiological control of the site during operation*

Mobilization and hospitalization Patients were allowed to get up as early and as much as they wanted even on the first days after the operation and no form of support was provided Training in active back exercises was given by the hospital physiotherapists during in patient treatment except for the first one or two days after the operation Out patients were advised to do exercises at home and were given an illustrated instruction sheet

Hospitalization was reduced to the time necessary for the completion of pre operative examinations for the wound to heal and for additional operations to be carried out Patients were discharged even if still bedridden

(d) *Analysis of findings*

All periods of time were recorded from the day of operation for group A and for group B from the day on which drug treatment was commenced by the hospital Where the operation in group A

was performed in two stages or where re-operation was necessary the time was recorded from the day of the first stage operation or first operation respectively

The findings were calculated on the basis of the total number of patients in each group In a few instances they were based on the number of examinations carried out and this will be pointed out where appropriate in the text

The standard error (S E) of the difference between two proportions was computed from the formula (HILL 1961)

$$S.E.\ (p_1 - p_2) = \pm \sqrt{Pq\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}$$

where N_1 N_2 = number of patients in the two groups
p_1 p_2 = proportion of patients in the two groups having the characteristic under discussion
P = $p_1 + p_2$
q = 100 − P

The significance of any difference between the proportions was assessed as follows

Value of $(p_1 - p_2) / S.E.$	*Statistical significance*
>3	Significant
$2-3$	Probable
<2	Insignificant

— Dr Bernhard Paus

Definitions

Certain terms frequently used in the text are defined as follows and are listed alphabetically

Adults individuals 15 years of age or above

Children individuals 1–14 years of age

Clinical kyphosis groups there are five of these groups (Fig 3) the criteria for which are as follows

Group	*Criteria*
0	No visible change in the back
1	Protrusion of spinous processes but no angulation
2	Slight but definite angulation
3	Marked angulation
4	Hunchback

Completely bedridden the patient was lying down the whole day except perhaps for a period of two hours at the most (see also *Completely up and about Partly bedridden*)

Completely up and about the patient was up and about the whole day except perhaps for a period of two hours at the most (see also *Completely bedridden Partly bedridden*)

Complete working capacity the patient was able to choose his type of work without having to take the condition of his back into consideration and was able to achieve a performance equal to that of other individuals engaged in similar type of work Housewives were said to have complete working capacity when they could carry out their housework without assistance For children the criterion was the ability to attend school play and run about like healthy children of the same age (see also *Partial working capacity*)



Figure 3 *Clinical kyphosis*

a *Kyphosis 1 — protrusion of spinous processes but no angulation of the spine*
b *Kyphosis 2 — slight but definite angulation of the spine*
c *Kyphosis 3 — marked angulation of the spine*
d *Kyphosis 4 — hunchback*

Early paraplegia paraplegia which began within two years of the appearance of the spinal symptoms (see also *Late paraplegia*)

Fusion bony union between the vertebral bodies appeared present in radiographs in both the antero posterior and the lateral views no distinction was made between complete and partial fusion

Large vertebral defect a defect measuring more than one half of the transverse sagittal or longitudinal axis of the vertebral body as seen on radiographs but without the body being sub totally or completely destroyed (see also *Small vertebral defect*)

Late paraplegia paraplegia which began more than two years after the appearance of the spinal symptoms (see also *Early paraplegia*)

Lower spinal lesion a lesion in which the lumbar region of the spine and the sacrum are involved (see also *Upper spinal lesion*)

Partial working capacity ability to work to a lesser extent than others engaged in the same type of work e g part time work light farm work or housework etc (see also *Complete working capacity*)

Partly bedridden (Partly up and about) anything between the extremes of completely bedridden and completely up and about

Previous medication medication with INH PAS or SM received before the first attendance at the out patient clinic but which ceased more than one month before medication was provided by the hospital if medication ceased less than one month before it was provided by the hospital it was regarded as pre operative medication

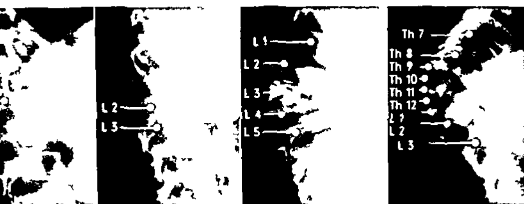


Figure 4 *Radiological groups*

a *Group 1 — changes of structure or small defects in 1–2 vertebrae*
b *Group 2 — changes of structure or small defects in 3–4 vertebrae large defects in 1–2*
c *Group 3 — changes of structure or small defects in 5–6 vertebrae large defects in 3–4 sub total or total destruction of 1–3 vertebrae*
d *Group 4 — changes of structure or small defects in 7 or more vertebrae large defects in 5 or more sub total or total destruction of 4 or more vertebrae*

Radiological deterioration an increase in the pathological changes as assessed from the radiographs

Radiological groups there are four of these groups (Fig 4) for which the criteria are as follows (it should be noted that the classification is not affected by the presence or otherwise of abscesses or kyphosis)

Group	*Criteria*
1	Changes of structure or small defects in 1–2 vertebrae
2	Changes of structure or small defects in 3–4 vertebrae large defects in 1–2
3	Changes of structure or small defects in 5 6 vertebrae large defects in 3–4 sub total or total destruction of 1–3
4	Changes of structure or small defects in 7 or more vertebrae large defects in 5 or more sub total or total destruction of 4 or more

Radiological improvement (i) a more normal appearance of the vertebral structure (ii) sharper contours (iii) a decrease in the defects present or at least no increase in such defects (Fig 5) (iv) fusion

Radiological kyphosis the angle between the axis of the spine above the lesion and the extension of the axis below the point at which the deformity was greatest (Fig 6)

Radiological no change no change in radiological findings or signs of both improvement and deterioration but to an equal extent Changes



Figure 5 *Decrease in defects after operation*
Case 14 — Female 22 years before operation and after 31 months



Figure 6 *Measurement of radiological kyphosis*
The kyphosis was measured as the angle between the axis of the spine above the lesion and the extension of the axis below it

in kyphosis and in abscess shadow were not taken into account in assessment of the radiological development

Recovery from paraplegia when any bladder or bowel symptoms had disappeared there was motor and sensible recovery and disappearance

of increased muscular tonus and of clonus where present while a slight increase of tendon reflexes and an inversion of plantar reflexes might persist

Slight complaints a feeling in the back which patients distinguished from ordinary pain and which might perhaps be a sensation of discomfort weakness tiredness or stiffness It could occur without any apparent cause or following a whole day of heavy farm or housework Patients would sometimes only notice the feeling and pay no more attention to it at other times they would change position or even stop working for a moment or a few minutes The term could also cover tenderness to direct or indirect pressure on the lesion

Small vertebral defect a defect which measured less than one half of the transverse sagittal or longitudinal axis of the vertebral body as seen on radiographs (see also *Large vertebral defect*)

Upper spinal lesion a lesion in which the cervical and dorsal regions of the spine are involved The term also covers lesions in which both the dorsal and lumbar regions are involved The inclusion of those which involve only the 12th dorsal and several lumbar vertebrae may perhaps be questioned This point however is of purely academic interest in the present investigation since such lesions were found in only two patients in whom Th12-L2 and Th12-L5 were affected (see also *Lower spinal lesion*)

The Investigation

1 Treatment with Anti Tuberculosis Drugs in Conjunction with Radical Operation Group A

2 Ambulatory Treatment with Anti Tuberculosis Drugs Group B

3 Other Groups of Patients

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Treatment with Anti-Tuberculosis Drugs in Conjunction with Radical Operation Group A

I Survey of Patients

The *age distribution* is given in Table 3. Of the total of 100 patients 42 were children (42.0 per cent) and 58 were adults (58.0 per cent). Their ages ranged from 17 months to 58 years. The age distribution of the Korean population is also given in Table 3 and there is on the whole good agreement between the age distribution of the patients and that of the population. However in the age range 25–44 there is a higher proportion among the patients and in the age range from 45 onwards the proportion of patients is lower. The group of patients included 43 males and 57 females.

TABLE 3 *Age distribution of 100 patients treated with anti-tuberculosis drugs in conjunction with radical operation for tuberculosis of the spine (Group A) and age distribution in the Korean population 1955 according to Korean Ministry of Public Health and Social Affairs (1957)*

Age Years	Patients Number		Patients Per cent		Korean population Per cent	
0–4	20	42	20.0	42.0	15.6	40.1
5–14	22		22.0		24.5	
15–24	19		19.0		20.1	
25–44	35		35.0		23.6	
45–59	4		4.0		10.9	
60 and above	–		–		5.3	
Total	100		100.0		100.0	

Information on *duration of symptoms* is given in Table 15 (see page 64) where it is discussed in connexion with the results of treatment. The range was from two months to seventeen to eighteen years.

The data on the *region of the spine involved*, assessed by radiographs were as follows

Region of spine	Number of lesions Children	Adults
Cervical	–	–
Cervico dorsal	4	3
Dorsal	14	14
Dorso lumbar	7	11
Lumbar	9	26
Lumbo sacral	8	6
Sacral	–	1
Total	42	61

It will be seen that there were 103 lesions among the 100 patients since three adults had double lesions (i e two lesions separated by at least one apparently normal vertebra) The data are summarized in Table 4

Vertebrae affected The frequency with which different vertebrae were involved is shown in Fig 7 and the number of vertebrae affected is given in Table 5 The 42 children had a total of 181 vertebrae affected and the 58 adults 235 vertebrae giving an average of 4 3 for the children and 4 0 for the adults Twenty eight patients (28 0 per cent) had one or two vertebrae affected

The distribution of *radiological groups* is shown in Table 6 children had lesions in groups 3 or 4 more often (33 out of 42 cases) than adults (29 out of 58 cases) No correlation was found between the duration of symptoms and radiological grouping The use of the classification systems suggested by HELLSTADIUS (1937) and ALVIK (1949) (see page 20) was made difficult by the extensive destruction in most cases probably 84 lesions should be classified as extensive or central and 10 as vesicular according to HELLSTADIUS and 96 as central according to ALVIK According to the classification suggested by FELLANDER (1954) 68 cases had a large abscess shadow on radiographs 25 had a small shadow while nothing definite could be said about abscess shadows in seven cases

Pulmonary and extrapulmonary complications Sixty eight patients (68 0 per cent) were found to be suffering from 86 complications 11 of the patients suffering from both pulmonary tuberculosis and extra pulmonary complications A total of 16 patients had more than one complication at the same time Pulmonary tuberculosis as determined by radiological examination was found in 31 patients (31 0 per cent 11 children and 20 adults) among these patients were cases with disseminated tuberculosis and with extensive infiltrations and cavities

TABLE 4 *Region of spine involved in 100 patients treated with anti-tuberculous drugs in conjunction with radical operation (Group A)*

Region of spine involved	Children		Adults		Total		
	Patients	Lesions	Patients	Lesions	Patients		Lesions
	Number	Number	Number	Number	Number	Per cent	Number
Upper spine	25	25	25	26	50	50.0	51[1]
Upper and lower spine	–	–	2	4	2	2.0	4[1]
Lower spine	17	17	31	31	48	48.0	48[1]
Total	42	42	58	61	100	100.0	103[1]

[1] The upper spine was involved in 53 lesions and the lower spine in [illegible] lesions

TABLE 5 *Vertebrae affected in 100 patients treated with anti-tuberculosis drugs in conjunction with radical operation (Group A)*

Number of vertebrae affected	Children	Adults	Total	
	Number	Number	Number	Per cent
1	–	1	1	1.0
2	6	21	27	27.0
3	10	11	21	21.0
4	9	8	17	17.0
5–9	17	14	31	31.0
10 or more	–	3	3	3.0
Total	42	58	100	100.0

TABLE 6 *Radiological grouping of 100 patients treated with anti-tuberculosis drugs in conjunction with radical operation (Group A)*

Radiological group	Children	Adults	Total	
	Number	Number	Number	Per cent
1	1	1	2	2.0
2	8	28	36	36.0
3	21	21	42	42.0
4	12	8	20	20.0
Total	42	58	100	100.0

formation was provided by the author's successor[1] thus allowing an observation period of twenty eight to thirty months to be achieved the findings were the same in both cases as those of the author after twenty to twenty one months of observation

2 Treatment

Medication with anti tuberculosis drugs Previous medication had been received by 22 patients

The doses given by the hospital were those set out elsewhere (see page 30) Data on pre operative treatment with INH and PAS are given in Table 25 (see page 68) Medication lasted from three days to eight years and was less than one month in 30 patients and less than two months in 54 patients Additional SM was given for less than one week in 42 patients for one to two weeks in 31 patients and for more than two weeks in 27 patients

Post operative treatment with INH and PAS was shorter than twelve months for 18 patients These failed to come for control examinations when traced at the last follow up examination it was learned that the reason for their not coming was that they had felt completely well In 39 patients the treatment lasted longer than the planned twelve to eighteen months partly as a result of persistent symptoms but partly also because the doctor at the out patient clinic gave further drugs at the control examination solely from habitual practice Post operative medication with SM usually coincided with post-operative hospitalization

To investigate whether ambulatory patients were taking their drugs as instructed 100 check examinations for PAS in urine were carried out in patients selected at random in the middle of the investigation period and without the patients knowing that such a test was being done The reaction was positive in 79 cases and negative in 13 in the remaining 8 cases the patients stated that their supplies of PAS had been used up during the previous eight to ten days and volunteered this information before they were confronted with the results of the test

Data on *recumbency* estimated as the interval between the operation and when the patients were completely up and about are given in Table 7 it was less than three months in 43 patients 43 0 per cent and less than six months in 71 cases 71 0 per cent

[1] Dr H Thrap Meyer Head of the Department of Orthopaedic Surgery The National Medical Center in Korea 1962

TABLE 7 *Recumbency in 100 patients treated with antituberculous drugs in conjunction with radical operation (Group A) based on the interval between operation and the time when the patients were completely up and about*

Recumbency	Children	Adults	Total	Cumulative total	
	Number	Number	Number	Number	Per cent
Less than 1 month	10	–	10	10	10 0
1–3 months	15	18	33	43	43 0
3–6	12	16	28	71	71 0
6–12	3	15	18	89	89 0
12 24 months	1	4	5	94	94 0
Partly or completely bed ridden at last follow up examination	–	3	6	100	100 0
Dead while still bedridden	1	2			
Total	42	58	100	100	100 0

Immobilization The first five patients were provided with plaster beds and body casts but their use was not enforced as a result plaster beds were generally found on the floor under the patient s bed while body casts were removed by the patients on their return home No means of immobilization were provided for the next 95 patients

Hospitalization Of the 100 patients six orphans were admitted from — and discharged to — institutions with hospital facilities In the remaining 94 cases hospitalization lasted on the average for thirty five days (Table 8) it was within the planned period of four to six weeks for 67 patients out of these 94 (71 2 per cent) and for five of the remaining six patients A study of the 27 patients who were hospitalized for more than forty days shows that 12 of them had pulmonary tuberculosis or extraspinal bone and joint tuberculosis and 10 had paraplegia

TABLE 8 *Duration of hospitalization of 94 out of 100 patients treated with antituberculous drugs in conjunction with radical operation (Group A)*[1]

Hospitalization Days	Children	Adults	Total	Cumulative total	
	Number	Number	Number	Number	Per cent
13 21	16	12	28	28	29 8
22–30	8	18	26	54	57 5
31–40	2	11	13	67	71 2
41 60	6	10	16	83	88 3
61 and above	4	7	11	94	100 0
Total	36	58	94	94	100 0

[1] Six patients who were admitted from and discharged to institutions with hospital facilities are not included

Op rations

Type of operation	*Number of patients*	*Remarks*
One stage	97	–
Two stage	2	Double lesion in spine
	1	Extensive lesion
Re-operation once	10	Residual abscess and possible sinus formation
Re operations three times	1	
Additional operations	5	Tuberculosis of the hip (2 cases) I neo sacroiliac joint and pubic bone (1 case each)

All re operations were carried out within three to fourteen months of the original operation except the third re operation in one case which was re operated three times

3 Operative Findings

Gross pathology was found in 99 out of the 100 cases The macroscopic findings were as follows

Findings	*Number of cases*
Pus and/or caseous material	85
Granulation tissue and/or bone sand	96
Bone and/or disc sequestrum	92

The dividing line between bone sand and bone sequestrum was taken as 3–4 mm in any dimension (Fig 8)

No abscess was found on operation in five cases out of 68 with a large abscess shadow on the radiograph and in eight cases out of 25 with a small shadow

The *microbiological and histological findings* are shown in Table 9 acid fast bacilli were found in 53 cases and not found in 40 cases

Tuberculous granulation tissue was found in 73 cases and probable tuberculosis in one a total of 74 cases Necrosis was found in 64 cases corresponding to 64 0 per cent of the total and 86 5 per cent of the 74 cases with tuberculous granulation tissue

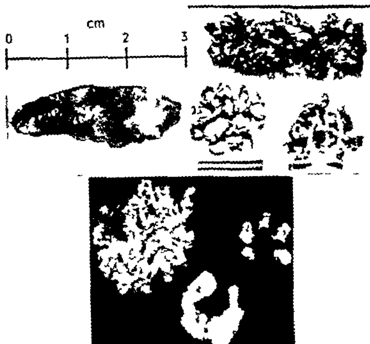


Figure 8 *Bone and disc sequestra*

TABLE 9 *Microbiological and histological findings in material removed by operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Histological findings	Microbiological findings			Total
	Acid fast bacilli		No examination	
	Present	Not present		
	Number	Number	Number	Number
Tuberculous granulation tissue	46	24	4	74
Chronic inflammation without definite evidence of tuberculosis	6	13	2	21
Bone tissue cartilage fibrous tissue	–	2	1	3
No histological examination	1	1	–	2
Total	53[1]	40[2]	7	100

[1] 35 by culture 18 by direct examination
[2] 37 by culture 3 by direct examination

4 — Dr Bernhard Paus

The pre operative diagnosis of tuberculosis was verified or supported by laboratory findings as follows

Findings	*Number of cases*	*Cumulative total*
Acid fast bacilli and tuberculous granulation tissue	46	46
Acid fast bacilli only	7	53
Tuberculous granulation tissue only	28	81

In spite of the finding of acid fast bacilli the histological examination in six cases showed 'only chronic inflammation

Acid fast bacilli were found more than twice as often in cases where histological examination showed necrosis (43 cases out of 64) as in the cases without necrosis (9 out of 34)

The one patient with no gross pathological changes at operation showed bone tissue cartilage and fibrous tissue by histological examination unfortunately no examination for tubercle bacilli was made He had suffered from the disease for six years five of them with paraplegia treatment during these five years had been with INH while SM was given during an eighteen month period from May 1957 to November 1958 The operation was performed in April 1959 He was operated on for a tumour on the upper arm in April 1960 histological examination showed tuberculous granulation tissue with necrosis

4 Results of Treatment

(a) *Clinical findings*

The data on *back pain* were as follows

Time	*Patients with back pain*	*Patients without back pain*
Before operation	90	10
After operation (at last follow up examination or when last seen)	6	94

In 46 cases the patients stated that the pain more or less disappeared from the day of the operation

Ability to be up and about The condition of the patients before operation was as follows

Condition	*Number of patients*
Completely bedridden (includes one case where this was due to tuberculosis of the hip)	76
Partly bedridden	13
Completely up and about	11

By the end of the period of observation 94 patients (94 0 per cent) were completely up and about or had been so at the last control examination as shown in Table 7 three patients were completely or partly bedridden and the remaining three had died while still completely bedridden

Working capacity Of the 27 adult men 16 were farmers or heavy labourers while 27 of the 31 adult females did housework the remainder were sales personnel office workers students etc Their condition before operation was as follows

Condition	*Number of patients*
Complete incapacity to work	94
Partial working capacity	4
Complete working capacity	2

The incapacity had lasted from two to three months to more than fifteen years

The working capacity among the patients at the last follow up examination is shown in Table 10 from which it will be seen that 80 patients (80 0 per cent) had complete working capacity of this group 50 were free from clinical symptoms or signs except for kyphosis in some cases while 30 had slight complaints A further six patients (6 0 per cent) had partial working capacity the failure to achieve complete capacity being due to pain slight complaints and fear of damaging the spine in five cases in the sixth case bilateral pulmonary tuberculosis and polyarthritis were the probable causes but a contribution by the spinal disease cannot be excluded

Six patients (6 0 per cent) were incapacitated as a result of the spinal disease and two patients (2 0 per cent) as a result of other diseases

Of the four patients (4 0 per cent) who died one was able to work before death occurred while the remaining three were not these patients are discussed later (see page 61)

Two patients (2 0 per cent) were not traced at the last follow up examination but both had complete working capacity when last seen six and nine months after operation respectively and one was said at the time of the last examination to have been recently seen at work as a shoemaker

Slight complaints were found in 34 patients (34 0 per cent eight children 26 adults) after operation

General mobility was poor in 91 patients before operation it was good in 84 after operation

TABLE 10 *Working capacity two to two and a half years after operation in 100 patients treated with anti-tuberculosis drugs in conjunction with radical operation (Group A)*

Working capacity	Children		Adults		Total	
	Number	Per cent	Number	Per cent	Number	Per cent
Complete						
No clinical symptoms or signs	32 } 40	76.1 } 95.2	18 } 40	31.0 } 69.0	50 } 80	50.0 } 80.0
Slight complaints	8	19.1	22	38.0	30	30.0
Partial	–	–	6	10.3	6	6.0
Incapacity						
Due to the spinal disease: paraplegia (2), back pain and sinus (4)	–	–	6	10.3	6	6.0
Due to other disease: tuberculosis of kidney (1), gastric trouble of uncertain character (1)	–	–	2	3.4	2	2.0
Dead						
Able to work before death (1), died being still unable to work (3)	1	2.4	3	5.2	4	4.0
Not traced						
But with complete working capacity when last seen	1	2.4	1	1.8	2	2.0
Total	42	100.0	58	100.0	100	100.0

The available information shows that *tenderness* was originally present in 75 out of 83 patients; no tenderness was reported in 72 out of 82 patients after operation.

Paraplegia. A total of 21 patients (eight children, 13 adults) were suffering from paraplegia before operation and the condition had been present for a period ranging from one month to nearly five years; the 21 cases could be divided into 17 early and four late and 11 complete and 10 incomplete. Of these patients 16 (seven children and nine adults) recovered completely, but one of the adults had nevertheless only partial working capacity; this was the patient mentioned above who was suffering from bilateral pulmonary tuberculosis and polyarthritis. An analysis of the results is given in Table 11. Recovery was complete within three months in 10 cases and within three to six months in six (Fig. 4); no recovery was observed later than six months.

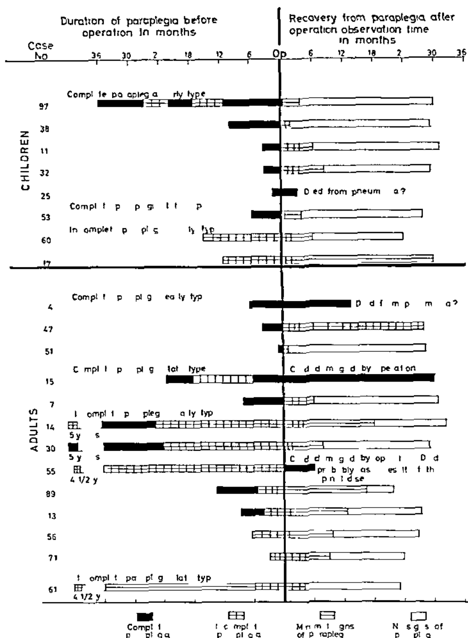


Figure 9 *Pecovery from paraplegia in 21 patients treated with anti tuberculosis drugs in conjunction with radical operation*

TABLE 11 *Recovery from paraplegia in 21 patients treated with anti tuberculosis drugs in conjunction with radical operation*

Degree of recovery	Children	Adults	Total
	Number	Number	Number
Complete	7	9	16
Partial	—	1	1
None	—	1	1
Dead as paraplegic	1	2	3
Total	8	13	21

Sinus was present in 21 patients (five children 16 adults) before operation and had been draining for a period in the range three months to five years It healed within one month of operation in 13 cases within twelve months in all of the children and in 14 of the adults No sinus healed after that time

The *body weight* before operation was 40–60 kg with an average of 49 5 kg in the 58 adult patients The following changes in weight took place during the period of observation

Weight changes	*Number of patients*
Increase	35
Decrease	8
None	6
Not measured	9

The increase or decrease was usually 3–4 kg

Erythrocyte sedimentation rate A value of 1–9 mm/1 hr for the ESR was found before operation in 13 patients with florid disease the following is a typical case

Case 61 a 37 year old Male Duration of disease four years Group 4 lesion of Th10 L3 Incomplete paraplegia On operation large amount of pus sequestra etc Acid fast bacilli found by culture Tuberculous granulation tissue with necrosis found on histological examination ESR 6 mm/1 hr

Of 20 patients with an ESR of 50 mm/1 hr or more 19 suffered from complications in the form of pulmonary tuberculosis, tuberculosis of other organs sinus or paraplegia

The ESR observed is shown in Table 12 it will be seen that ESR improved markedly in the first six months after operation after which there was little change A high ESR was sometimes found even though the spinal disease was probably inactive as in the following case

Case 29 a 20 year old Male Duration of disease four years Sinus Group 3 lesion of L1–3 Sinus healed within one month of operation After one year started light farm work At follow up examination after 28 months no clinical symptoms or signs except kyphosis for the last 18 months Radiograph fusion within 10 months of operation ESR values

Date	*ESR mm 1 hr*
May 1959 (before operation)	54
May 1960	10
November 1960	35
March 1961	14
September 1961	36

No symptoms or signs of other disease found No pathological condition shown by radiographs of the lungs

TABLE 12 *ESR in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group 1)*

ESR mm/1 hr	On admission for operation	6 months after operation	12 months after operation	Last follow up examination
	Number	Number	Number	Number
1–9	13	31	33	37
10–19	19	28	30	25
20–29	25	14	10	21
30–49	23	6	8	3
50–	20	5	2	3
Dead ESR influenced by pregnancy or intercurrent diseases or not examined	–	16	17	11
Total number of patients	100	100	100	100

Measurements of *haemoglobin* gave the following results

Time	*Hgb* (*gram per cent*)	*Average Hgb* (*gram per cent*)
Before operation	8 4–15 7	12 1
Last follow up examination	10 1–16 3	13 1

(b) *Radiological findings*

It will be recalled that there were 103 lesions among the 100 patients in the group (see page 42) As shown in Table 13 there was *improvement* in 81 lesions (31 children with 31 lesions and 48 adults with 50 lesions) representing 78 6 per cent of the total number of



Figure 10 *Development of fusion within four to six months*
Case 37 — Female 39 years Th 10–11 before operation and after five and after thirty months

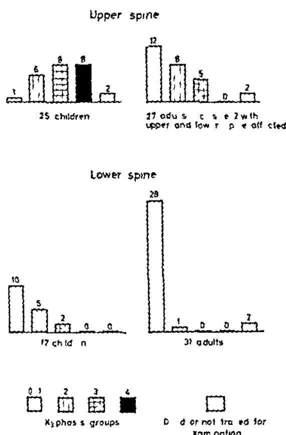


Figure 11 *Gibbus and kyphosis in 100 patients treated with anti-tuberculous drugs in conjunction with radical operation and followed up after two to two and a half years*

TABLE 15 *Interval between operation and full resumption of work in 100 patients treated with anti tuberculous drugs in conjunction with radical operation (Group A)*

Interval	Children		Adults		Cumulative total	
	Number	Per cent	Number	Per cent	Number	Per cent
Less than 3 months	13	31.0	2	3.4	15	15.0
3–6 months	19	45.2	11	19.0	45	45.0
6–9	7	16.6	11	19.0	63	63.0
9–12	—		11	19.0	74	74.0
12–30	1	2.4	5	8.6	80	80.0
Partial working capacity, incapacity, dead or not traced	2	4.8	18	31.0	100	100.0
Total	42	100.0	58	100.0	100	100.0

TABLE 16 *Changes in radiological kyphosis two to two-and-a-half years after operation in 103 lesions in 100 patients treated with anti tuberculous drugs in conjunction with radical operation (Group A)*

Changes	Lesions of the upper spine		Lesions of the lower spine		Total lesions	
	Children	Adults	Children	Adults		
	Number	Number	Number	Number	Number	Per cent
Increase 10–50	16	7	1	3	27	26.2
Decrease 20	1	—	—		1	1.0
No change	6	19	16	27	68	66.0
Patients dead or not traced	2	2		3	7	6.8
Total	25	28	17	33	103	100.0

It would be reasonable to suspect a clinical kyphosis in group 4 (hunchback) to have some effect on the working capacity because of its possible influence on respiration and circulation; such an effect could not be demonstrated since all eight children with clinical kyphosis in group 4 were found to have complete working capacity. Neither could an effect be demonstrated with regard to slight complaints since seven had no clinical symptoms or signs other than kyphosis. Only one patient had slight complaints. A similar experience was reported by ALVIK (1949).

(c) *Complications during treatment*

The following complications occurred during treatment

Complication	*Number of patients*
Damage to cord	2
Lesion of pleura	17
Lesion of inferior vena cava	1
Bloody sputum	1
Sloughing or rupture of the wound	16
Sinus formation in the wound	4
Lesion of lumbar nerve root	2
Post operative meteorism for 10 days	1
Intolerance to PAS	2
Intolerance to SM	2

The only serious complications were two instances of damage to the cord during surgery and subsequent complete paraplegia Both these patients were suffering from incomplete paraplegia before operation One showed signs of meningitis after four days (headache stiff neck fever Gram negative bacilli in pure culture in the spinal fluid) but these disappeared completely in eight to ten days after chloramphenicol had been administered

The 17 lesions of the pleura occurred in the course of the 49 costo transversectomies or rib resections performed none gave rise subsequently to any difficulties

The inferior vena cava was taken for the abscess wall in one case and incised the incision was sutured and there were no subsequent difficulties

Bloody sputum, or rather bloody water in the mouth when the wound was flushed before closure was seen in the following case

Case 68 A three year old girl Group 4 lesion of Th6–10 Radiography before operation showed a fusiform paravertebral abscess shadow with a tent like projection on the left side Since it is believed that the pleura was not injured during surgery the case was probably an example of the penetration of the lung by the abscess as described by HODGSON & STOCK (1960a) There was no lung reaction after operation and the post operative course was uneventful Discharged after fifteen days

Sloughing or ruptures of the wound healed after a few weeks sinuses after two to eight months

The lesions of the lumbar nerve roots gave rise to lasting hypaesthesia and to weakness of the quadriceps Post operative meteorism for ten days was seen after a costotransversectomy but not after any of the 10 transperitoneal operations

No spread of pulmonary tuberculosis was ever seen and meningitis only in the one case mentioned

(f) *Re-operations failures and relapses*

A total of 11 patients (11 0 per cent) underwent re operation for residual abscess and possible sinus

The following are the data on failures and relapses

Condition	*Number of patients*
Complete incapacity for work during the whole observation period	4
Relapse after temporary complete capacity	2
Partial working capacity at end of period	6
Temporary relapse	1
Incapacity for work owing to other disease	2

The causes of the failure of working capacity have already been mentioned (see page 51)

(g) *Mortality*

This was nil in the immediate post operative period but one of the two patients with surgical damage to the cord died after five months and may possibly be regarded as an operative fatality

A boy with paraplegia died after three months he was said to have developed a high fever with cough rusty expectorate and dyspnoea and died in a few days A woman with paraplegia died after twelve to thirteen months the cause was said to be pneumonia but no details were available In neither case had the paraplegia improved before death

A man died after twenty three months when last in contact with the hospital he had been in full time employment as a clerk from three to twelve months after operation No information could be obtained on his working capacity during the last year of life or on the cause of death

3 Effect of Various Factors on Prognosis

(a) *Operation*

The effect of operation on the results of treatment will be considered separately when comparing group A and group B (see page 103)

(b) *Observation period*

There were some individual changes in working capacity as found twelve months and two to two and a half years *after operation* but the total number of patients with complete working capacity was practically unchanged six patients recovered complete working capacity during this period while three patients either relapsed became unable to work because of other disease or died

No effect of the duration of the observation on the incidence of slight complaints was found, as shown below

Observation (months)	*Number of patients with slight complaints*	*Total number of patients examined*
28–34	20	56
22–27	14	38

The effect of the duration of observation on the radiological findings is difficult to determine with certainty as only 72 patients were examined radiologically after ten to fourteen months out of 94 patients seen at the last follow up examination Among these 72 patients, none showed deterioration between the two examinations, while nine of 17 patients with no change or with deterioration after twelve months showed improvement at the last examination Fusion had developed after the twelve months examination in six cases

(c) *Age*

Data on working capacity have been presented in Table 10 The difference between the proportion of children with complete working capacity (95 2 per cent) and of adults (69 0 per cent) is 26 2 per cent The difference is significant as it is more than three times the standard error for this difference (±8 1 per cent) A further breakdown of the age groups is presented in Table 17

TABLE 17 *Effect of age on working capacity two to two and a half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Age Years	*Working capacity*			Total
	Complete	Partial	Incapacity for work dead or not traced	
	Number	Number	Number	Number
0–4	18	–	2	20
5–14	22	–	–	22
15–24	13	1	5	19
25–44	23	5	7	35
45–59	4	–	–	4
Total	80	6	14	100

The effect of age on other relevant features is summarized below

Feature	*Effect of age*	*Remarks*
Slight complaints	Less frequent in children (8 out of 42) than in adults (26 out of 58)	(See page 51) Caution is necessary in comparison of subjective information of this type
Recumbency	Shorter in children than in adults	See Table 7
Interval between operation and full resumption of work	Shorter in children than in adults	See Table 15
Fusion	More frequent in adults (68 8 per cent) than in children (40 5 per cent)	See Table 13 difference (28 3 per cent) nearly three times standard error ($\pm$ 9 9 per cent)
Radiological improvement	None (adults 82 0 per cent children 73 8 per cent)	See Table 13 difference (8 2 per cent) equal to standard error ($\pm$ 8 - per cent)
Recovery from paraplegia	None	See Table 11 small group only
Healing of sinus	None	See page 54 small group only
Wound complications	None complications occurred in 8 children out of 42 and 12 adults out of 58	See page 60
Clinical kyphosis and change in radiological kyphosis	Effect discussed below	See Figure 11 Table 16 and page 70

(d) *Duration of symptoms*

This had no effect either on the ensuing working capacity (Table 18) or the radiological findings (Table 19) The proportion of children with complete working capacity is the same within all groups as is also the case with adults with a history of less than one year and upwards of five years Twenty four adults out of 32 (75 0 per cent) with a history of less than three years had complete working capacity and 16 out of 26 adults (61 5 per cent) with a history of more than three years The difference 13 5 per cent is insignificant (the standard error of this difference being $\pm$ 12 2 per cent)

Fifty four lesions out of 67 (80 6 per cent) with a history of less than three years showed radiological improvement and 27 out of 36 (75 0 per cent) with a history of upwards of three years

No effect of the duration of the observation on the incidence of slight complaints was found as shown below

Observation (months)	*Number of patients with slight complaints*	*Total number of patients examined*
28–34	20	6
22–27	14	38

The effect of the duration of observation on the radiological findings is difficult to determine with certainty as only 72 patients were examined radiologically after ten to fourteen months out of 94 patients seen at the last follow up examination Among these 72 patients, none showed deterioration between the two examinations, while nine of 17 patients with no change or with deterioration after twelve months showed improvement at the last examination Fusion had developed after the twelve months examination in six cases

(c) *Age*

Data on working capacity have been presented in Table 10 The difference between the proportion of children with complete working capacity (95 2 per cent) and of adults (69 0 per cent) is 26 2 per cent The difference is significant as it is more than three times the standard error for this difference (± 8 1 per cent) A further breakdown of the age groups is presented in Table 17

TABLE 17 *Effect of age on working capacity two to two-and-a half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Age Years	Working capacity: Complete	Partial	Incapacity for work dead or not traced	Total
	Number	Number	Number	Number
0–4	18		2	20
5–14	22	–	–	22
15–24	13	1	5	19
25–44	23	5	7	35
45–59	4	–	–	4
Total	60	6	14	100

Region of spine	Lesions with fusion Number	Lesions with fusion Per cent	Total number of lesions
Children			
Upper spine	8	32.0	25
Lower spine	9	53.0	17
Adults			
Upper spine	19	68.0	28
Lower spine	23	70.0	33

The difference in children 21.0 per cent is insignificant (less than twice the standard error of this difference ± 15.4 per cent)

The effect of the region of the spine involved on clinical kyphosis and changes in radiological kyphosis is discussed below

TABLE 20 *Effect of region of spine involved on complete working capacity two to two-and-a half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Region of spine	Children		Adults	
	Complete working capacity	Total in group A	Complete working capacity	Total in group A
	Number	Number	Number	Number
Upper spine	23	25	17	25
Upper and lower spine	–	–	1	2
Lower spine	17	17	22	31
Total	40	42	40	58

TABLE 21 *Effect of region of spine involved on radiological findings two to two and a half years after operation in 103 lesions in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Region of spine	Radiological findings					Total	Fusion
	Improvement	No change	Deterioration	Interpretation not possible	Dead or not traced		
	Number	Number	Number	Number	Number	Number	Number
Upper spine	38[1]	6	1	4	4[1]	53[1]	27
Lower spine	43[1]	3	–	1	3[1]	50[1]	32
Total	81[1]	9	1	5	7[1]	103[1]	59

[1] Three patients had double lesions two of these showed improvement in both lesions and one patient had died

(f) *Radiological grouping*

This had no effect on working capacity (Table 22) and hardly any on the radiological findings (Table 23). The proportion of children with complete working capacity is the same in all groups among adults 20 out of 29 with lesions in the radiological groups 1–2 had complete working capacity and also 20 out of 29 lesions in groups 3–4. Thirty-four out of 38 lesions (89.5 per cent) in the radiological groups 1–2 showed radiological improvement compared with 47 out of 65 lesions (72.3 per cent) in groups 3–4. The difference 17.2 per cent is on the borderline between insignificance and probability (being only slightly more than twice the standard error for this difference, ±8.4 per cent).

TABLE 22. *Effect of radiological grouping on complete working capacity two to two-and-a-half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Radiological group	Children		Adults	
	Complete working capacity	Total in group A	Complete working capacity	Total in group A
	Number	Number	Number	Number
1	1	1	1	1
2	8	8	19	28
3	19	21	14	21
4	12	12	6	8
Total	40	42	40	58

TABLE 23. *Effect of radiological grouping on radiological findings two to two-and-a-half years after operation in 103 lesions in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Radiological group	Radiological findings					Total
	Improvement	No change	Deterioration	Interpretation not possible	Dead or not traced	
	Number	Number	Number	Number	Number	Number
1	2		–	–	–	2
2	3[illegible]	2	–	1	1	36
3	32	6	–	–	4	42
4	1[illegible][1]	1	1	4	2[1]	23[1]
Total	81	9	1	5	7[1]	103[1]

[1] Three patients had [illegible]; two of these showed improvement in both lesions and [illegible]

(g) *Pulmonary and extrapulmonary complications*

There was no harmful effect of these on working capacity (Table 24) a higher proportion of adults with pulmonary tuberculosis namely 18 out of 20 patients (90 0 per cent) had complete working capacity as compared with adults without pulmonary tuberculosis namely 22 out of 38 patients (58 0 per cent) the difference 32 0 per cent is more than twice the standard error (± 12 8 per cent) but it is reasonable to assume that this is explained by the influence of factors other than tuberculosis of the spine (see page 94) In two cases out of 21 with paraplegia surgical damage occurred to the cord Such damage did not occur in any of the 29 cases without paraplegia operated upon in the same regions and in the same way

TABLE 24 *Effect of pulmonary and extrapulmonary complications on complete working capacity two to two-and-a half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Condition	*Children*		*Adults*	
	Complete working capacity	Total in group A	Complete working capacity	Total in group A
	Number	Number	Number	Number
Pulmonary tuberculosis present	11	11	18	20
Pulmonary tuberculosis absent	29	31	22	38
Paraplegia present	7	8	8	13
Paraplegia absent	33	34	32	45
Sinus present	5	5	11	16
Sinus absent	35	37	29	42
Extrapulmonary tuberculosis present	2	3	7	10
Extrapulmonary tuberculosis absent	38	39	33	48

(h) *Anti tuberculosis medication*

Previous medication had no harmful effect on the working capacity of a group of 22 patients (nine children 13 adults) all became completely able to work The figures were too small to show whether previous medication had any beneficial effect An increase in the pre operative medication time from less than one month to one to six months affected neither the working capacity (Table 25) nor the

(f) *Radiological grouping*

This had no effect on working capacity (Table 22) and hardly any on the radiological findings (Table 23) The proportion of children with complete working capacity is the same in all groups among adults 20 out of 29 with lesions in the radiological groups 1–2 had complete working capacity and also 20 out of 29 lesions in groups 3–4 Thirty four out of 38 lesions (89 5 per cent) in the radiological groups 1–2 showed radiological improvement compared with 47 out of 65 lesions (72 3 per cent) in groups 3–4 The difference 17 2 per cent is on the borderline between insignificance and probability (being only slightly more than twice the standard error for this difference ±8 4 per cent)

TABLE 22 *Effect of radiological grouping on complete working capacity two to two-and-a half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Radiological group	Children		Adults	
	Complete working capacity	Total in group A	Complete working capacity	Total in group A
	Number	Number	Number	Number
1	1	1	1	1
2	8	8	19	28
3	19	21	14	21
4	12	12	6	8
Total	40	42	40	[illegible]8

TABLE 23 *Effect of radiological grouping on radiological findings two to two-and-a half years after operation in 103 lesions in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Radiological group	Radiological findings					Total
	Improvement	No change	Deterioration	Interpretation not possible	Dead or not traced	
	Number	Number	Number	Number	Number	Number
1	2	–	–	–	–	2
2	32	2	–	1	1	36
3	32	6	–	–	4	42
4	1[illegible] [1]	1	1	4	2[1]	23[1]
Total	81	9	1	[illegible]	7[illegible]	103[1]

[1] Three patients had double lesions two of these showed improvement in the lesions and one patient had died

(g) *Pulmonary and extrapulmonary complications*

There was no harmful effect of the e on working capacity (Table 24) a higher proportion of adults with pulmonary tuberculosis namely 18 out of 20 patients (90 0 per cent) had complete working capacity as compared with adults without pulmonary tuberculosis namely 22 out of 38 patients (58 0 per cent) the difference 32 0 per cent is more than twice the standard error (± 12 8 per cent) but it is reasonable to assume that this is explained by the influence of factors other than tuberculosis of the spine (see page 94) In two cases out of 21 with paraplegia surgical damage occurred to the cord Such damage did not occur in any of the 29 cases without paraplegia operated upon in the same regions and in the same way

TABLE 24 *Effect of pulmonary and extrapulmonary complications on complete working capacity two to two-and a half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group A)*

Condition	Children		Adults	
	Complete working capacity	Total in group A	Complete working capacity	Total in group A
	Number	Number	Number	Number
Pulmonary tuberculosis present	11	11	18	20
Pulmonary tuberculosis absent	29	31	22	38
Paraplegia present	[illegible]	8	8	13
Paraplegia absent	33	34	32	45
Sinus present	5	5	11	16
Sinus absent	3[illegible]	3[illegible]	[illegible]9	42
Extrapulmonary tuberculosis present	2	3	[illegible]	10
Extrapulmonary tuberculosis absent	38	39	33	48

(h) *Anti tuberculosis medication*

Previous medication had no harmful effect on the working capacity of a group of 22 patients (nine children 13 adults) all became completely able to work The figures were too small to show whether previous medication had any beneficial effect An increase in the pre operative medication time from less than one month to one to six months affected neither the working capacity (Table 25) nor the

radiological findings (Table 26) The number of patients with pre operative medication of six to twelve months and from twelve months and upwards is too small for appraisal although brief reference to this aspect is made on page 116 and in Table 55

A possible effect of the duration of the post operative medication is difficult to assess since it could be affected by the presence or absence of symptoms patients without symptoms were likely to discon

TABLE 25 *Effect of duration of pre-operative medication with INH and PAS on complete working capacity two to two-and-a half years after operation in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group 4)*

Duration of pre-operative medication with INH and PAS	Children		Adults		Total	
	Complete working capacity	Total in group A	Complete working capacity	Total in group A	Complete working capacity	Total in group A
	Number	Number	Number	Number	Number	Number
Less than 1 month	13	14	9	16	22	30
1–6 months	23	24	24	34	47	58
6–12	2	2	3	3	5	5
12 months to 8 years	2	2	4	5	6	[illegible]
Total	40	42	40	58	80	100

TABLE 26 *Effect of duration of pre operative medication with INH and PAS on radiological findings two to two-and-a half years after operation in 103 lesions in 100 patients treated with anti tuberculosis drugs in conjunction with radical operation (Group 4)*

Duration of pre operative medication with INH and PAS	Radiological findings					Total lesions
	Improvement	No change	Deterioration	Interpretation not possible	Dead or not traced	
	Number	Number	Number	Number	Number	Number
Less than 1 month	23[1]	2	–	3	3	31[1]
1–6 months	4[illegible]	6	1	2	4[1]	59[1]
6–12	5	–	–	–	–	5
12 months to 8 years	[illegible]	1	–	–	–	8[1]
Total	[illegible]	[illegible]	1	5	[illegible]	103[1]

[1] Three pat [illegible] f these showed improvement in both [illegible]

tinue medication (see page 46) while patients with persisting symptoms were likely to continue it However in a group of 18 patients (11 children and seven adults) with post operative medication of less than twelve months all the children and six out of the seven adults had complete working capacity

(i) *Duration of recumbency*

Its possible effect is difficult to assess since the duration of recumbency also could be affected by the presence or absence of symptoms Early ambulation appeared however to have no harmful effect on the final complete working capacity

Patients completely up and about within three months of operation	*Number with complete working capacity*	*Total number in group*
Children	24	25
Adults	16	18

(j) *Hospitalization*

A short hospital stay had no effect on the working capacity in a group of 28 patients (16 children and 12 adults) hospitalized for less than twenty one days all became completely able to work

(k) *Recovery from paraplegia effect of duration and type*

None of the patients had suffered from paraplegia for more than five years within that limit its duration had no effect on recovery e g four out of five patients with paraplegia of three to five years duration made a complete recovery

The effect of the type of paraplegia was as follows

Type of paraplegia	*Number with complete recovery*	*Total number in group*
Early	13	17
Late	3	4
Incomplete	9	10
Complete	7	11

(l) *Effect of various factors on clinical kyphosis and increase in radiological kyphosis*

Age the region of the spine involved and the extent of the lesion (radiological grouping) all affect the clinical kyphosis The data can be summarized as follows if in the case of the three adults with double lesions the more extensive of their lesions alone are taken into account (see also Fig 11 p 58)

Effect of *age* on clinical kyphosis

Age group	*Number with clinical kyphosis 3–4 after operation*	*Total number in group*
Children	18	42
Adults	5	58

Effect of the *region of the spine involved* and of *radiological grouping (extent of lesion)* on clinical kyphosis

Region of spine	*Children* *Number with clinical kyphosis 3–4*	*Children* *Total*	*Adults* *Number with clinical kyphosis 3–4*	*Adults* *Total*
Upper spine	16	25	5	27
Lower spine	2	17	–	31
Radiological group				
1–2	1	9	0	29
3	6	21	2	21
4	11	12	3	8

Increase in radiological kyphosis (Table 16) was also affected by age region of the spine involved and extent of the lesions

Effect of *age* on increase in radiological kyphosis

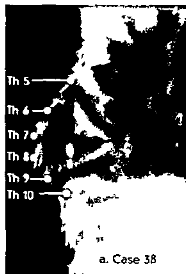
Age group	*Number with 10–50 increase in radiological kyphosis*	*Total number of lesions*
Children	17	42
Adults	10	61

Figure 12 *Kyphosis was not affected by early ambulation* ⟶

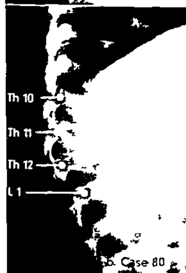
a *Case 38* *Female 3 years Th 5–9 in radiological group 4 Completely up and about within 1–3 months after operation Clinical kyphosis 2 before operation and 2 after 29 months radiological kyphosis 40 and 45°*

b *Case 60* *Male 1 year and 9 months Th 11 L 2 in radiological group 3 Completely up and about within 1 month after operation Clinical kyphosis [illegible] before operation and 2 after 24 months radiological kyphosis [illegible] and 35*

c *Case 4* – *Female [illegible] years [illegible] in radiological group [illegible] Completely up and about within 1–3 months after operation Clinical kyphosis 1 before operation and barely 1 after 28 months radiological kyphosis [illegible] and 30*


Th 5
Th 6
Th 7
Th 8
Th 9
Th 10
a. Case 38


a 29 months


Th 10
Th 11
Th 12
L 1
b. Case 80


b 24 months


L 3
L 4
L 5
c Case 34


months

Effect of the *region of the spine involved* and of *radiological grouping (extent of lesion)* on increase in radiological kyphosis

Region of spine	*Children* Number with 10°–50° increase in radiological kyphosis	*Total*	*Adults* Number with 10°–50° increase in radiological kyphosis	*Total*
Upper spine	16	25	7	28
Lower spine	1	17	3	33
Radiological group				
1–2	2	9	4	29
3–4	15	33	6	32

Twenty three out of 27 lesions with an increase of 10°–50° were upper spinal lesions In children such increase was seen more often in the radiological groups 3–4 while the existence of any difference was uncertain in adults

Early ambulation appeared to have no effect on the increase of radiological kyphosis (Fig 12) In spite of the small numbers, the considerations are limited to lesions in the upper spine and in the radiological groups 3–4

Recumbency	*Children* Number with 10°–50° increase in radiological kyphosis	*Total*	*Adults* Number with 10°–50° increase in radiological kyphosis	*Total*
Completely up and about within 3 months	8	13	1	6
Not completely up and about within 3 months	6	8	5	13

(m) *Failures*

All 12 patients with complete or partial working capacity because of their spinal disease at the last follow up examination were adults they had no other characteristic in common nor was there any other *feature which distinguished them from the other patients* They included members of both sexes the symptoms had lasted from less than one to more than fifteen years there were patients with upper spinal lesions and others with lower spinal lesions in the radiological groups 2–4 without complications and with pulmonary or extrapulmonary complications The ESR on admission for operation was in the range 9–114 mm 1 hr pre operative anti tuberculosis medication had lasted from less than one month to two to three years Many of these patients improved e g the back pain disappeared even if their working capacity was not fully restored

Ambulatory Treatment with Anti-Tuberculosis Drugs: Group B

A total of 45 patients were originally allotted to this group, of whom four children and four adults were excluded as follows:

Reason for exclusion	*Number of patients*
Disappeared after first examination; not even known whether treatment started	6
Irregular medication and attendance for control examinations	1
Went to another hospital	1

The number of patients remaining for study in group B was therefore 37.

1. Survey of Patients

The *age distribution* is shown in Table 27: there were 18 children and 19 adults, and the age range was two to 58 years; there were 22 males and 15 females.

TABLE 27. *Age distribution of patients receiving ambulatory treatment with anti-tuberculosis drugs for twelve months (Group B)*

Age	Patients	
Years	Number	Per cent
0-4	10 } 18	27.0 } 48.6
5-14	8	21.6
15-24	3	8.1
25-44	13	35.2
45-59	3	8.1
60 and above	–	–
Total	37	100.0

Duration of symptoms The symptoms had lasted from three months to twenty years

The data on the *region of the spine involved* were as follows

Region of spine	*Number of lesions* Children	Adults
Cervical	–	–
Cervico dorsal	1	–
Dorsal	4	3
Dorso lumbar	4	2
Lumbar	5	11
Lumbo sacral	5	3
Sacral	–	–
Total	19	19

There were 38 lesions among the 37 patients as one child had a double lesion namely a dorsal and a lumbo sacral The data are summarized in Table 28

TABLE 28 *Region of spine involved in 37 patients receiving ambulatory treatment with anti tuberculosis drugs for twelve months (Group B)*

Region of spine involved	Children		Adults		Total		
	Patients	Lesions	Patients	Lesions	Patients		Lesions
	Number	Number	Number	Number	Number	Per cent	Number
Upper spine	8	8	5	5	13	35 1	13[1]
Upper and lower spine	1	2	–	–	1	2 7	2[1]
Lower spine	9	9	14	14	23	62 2	23[1]
Total	18	19	19	19	37	100 0	38[1]

[1] The upper spine was involved in 14 lesions and the lower spine in 24 lesions

Vertebrae affected The frequency with which different vertebrae were involved is shown in Fig 13 The 18 children had a total of 78 vertebrae affected and the 19 adults a total of 64 vertebrae giving an average of 4 3 for the children and 3 4 for the adults Thirteen patients (35 1 per cent) had one or two vertebrae affected

The distribution of *radiological groups* is shown in Table 29 Children had lesions in groups 3–4 more often than adults—13 out of 18 cases and six out of 19 respectively

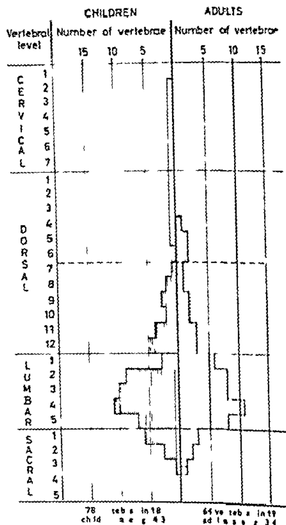


Figure 13 Vertebrae affected in 37 patients receiving ambulatory treatment with anti tuberculosis drugs

TABLE 29 *Radiological grouping of 37 patients receiving ambulatory treatment with anti tuberculosis drugs for twelve months (Group II)*

Radiological group	Children	Adults	Total	
	Number	Number	Number	Per cent
1	[illegible]	1	3	8
2	3	12	[illegible]	40
3	9	5	14	37.8?
4	4	1	[illegible]	[illegible]
Total	18	19	37	100.0

Pulmonary and extrapulmonary complications Twenty one patients (57 0 per cent) were found to have 27 complications two of the patients suffering from both pulmonary tuberculosis and extrapulmonary complications and six patients suffering from more than one complication at the same time Pulmonary tuberculosis as determined by radiological examination was found in six patients (16 2 per cent one child and five adults) among these one had extensive infiltrations and cavities Extrapulmonary complications were found in 17 patients (46 0 per cent eight children and nine adults)

Complications	*Number of complications* *Children*	*Adults*
Pulmonary tuberculosis	1	5
Paraplegia	2	–
Sinus formation	5	8
Extraspinal tuberculosis of bones and joints	–	2
Tuberculosis of urogenital organs and lymph glands	1	1
Tuberculosis of pericardium	–	1
Paralysis of both lower extremities following earlier poliomyelitis	1	–

The *Mantoux tuberculin test* was positive in all 37 patients in the group

Other tests The urine was cultured for tubercle bacilli either once or several times acid fast bacilli were found in one case and not found in 31 cases while no report was obtained in five cases

The VDRL slide flocculation test for syphilis was carried out in all patients except children under 5–6 years of age no seroreactors were found

The data on the *period of observation* are as follows

Observation (months)	*Number of patients*	*Cumulative total*
12	32	32
3–6	3	35
Dead	2	37

Thirty of the patients attended more or less regularly for control examinations at intervals of two to three months during the planned

treatment period of twelve months while five patients disappeared after continuing treatment for three to six months A search was made for these missing patients Two were eventually traced and examined bringing the total examined after twelve months to 32 Three could not be found and two patients had died

2 Treatment

Medication with anti tuberculosis drugs Previous medication had been received by six patients more than one month before treatment was begun by the hospital Five patients had received medication for periods ranging from three years to two months and in these patients there was no gap between this medication and the commencement of treatment by the hospital

INH and PAS were given for the entire year in the dosages planned in 29 cases INH alone in one case where PAS was not tolerated five patients stopped treatment after three to six months and two died SM was given in two cases admitted to the paediatric ward for six weeks and sixteen weeks respectively at the beginning of the treatment period

Data on *recumbency* estimated as the interval between the time when treatment was started by the hospital and when the patients were completely up and about are given in Table 30 as seen from the Table two patients were completely up and about from the start the number increased to five after three to six months and to 22 after twelve months

In no case was *immobilization* by plaster bed or body cast used no restriction was placed on the patients moving about

Hospitalization Apart from the two patients mentioned who were admitted to the paediatric ward no patients in the group were hospitalized during the twelve month investigation period One of these two was admitted for attempted suicide consequent on paralysis from previous poliomyelitis and one for tuberculous pericarditis as stated above hospitalization was for six weeks and sixteen weeks respectively Tuberculosis of the spine was diagnosed after admission

TABLE 30 *Recumbency in 37 patients receiving ambulatory treatment with anti tuberculosis drugs for twelve months (Group B) based on the interval from beginning of treatment by the hospital to the time when the patients were completely up and about*

Recumbency	Children	Adults	Total	Cumulative total	
	Number	Number	Number	Number	Per cent
Up and about from the beginning	2	–	2	2	5 4
Less than 1 month	–	–	–	2	5 4
1–3 months	–	–	–	2	5 4
3–6	3	–	3	5	13 5
6–12	10	7	17	22	59 5
Partly or completely bedridden after 12 months					
because of the spinal disease	–	9	9	32	86 5
because of other disease	1	–	1		
Dead still bedridden	–	2	2	37	100 0
Not traced for examination	2	1	3		
Total	18	19	37	37	100 0

3 Results of Treatment

(a) *Clinical findings*

The data on back pain were as follows

Time	*Patients with back pain*	*Patients without back pain*
Before treatment	37	0
After twelve months or when last seen	25	12

Ability to be up and about The situation before treatment was the following

Condition	Number of patients
Completely bedridden (includes one case where this was due to paralysis of both lower extremities following previous poliomyelitis)	31
Partly bedridden	4
Completely up and about	2

The changes during the twelve month treatment period can be seen from Table 30 the essential features being that complete ability to be up and about was found in 22 patients (59 5 per cent) nine patients remained bedridden because of spinal tuberculosis and one owing to previous poliomyelitis two had died while still completely bedridden and three could not be traced

Working capacity Four of the nine adult males were farmers or heavy labourers while nine of the 10 adult females did housework the remainder were sales personnel office workers students etc Their condition before treatment was started was as follows

Condition	*Number of patients*
Complete incapacity to work	35
Complete working capacity	2

The incapacity had lasted from two–three months to five years

The position at the end of the twelve month treatment period is shown in Table 31 It can be seen that a total of 13 patients (35 1 per cent 11 children and two adults) had complete working capacity of these six had no clinical symptoms or signs except possibly kyphosis while seven had slight complaints There were in addition six patients (16 2 per cent) with partial working capacity The condition of the remaining 18 patients can be seen from the Table

TABLE 31 *Working capacity after twelve months in 37 patients receiving ambulatory treatment with anti tuberculosis drugs (Group B)*

Working capacity	Children		Adults		Total	
	Number	Per cent	Number	Per cent	Number	Per cent
Complete						
No clinical symptoms or signs	6 } 11	33 3 } 61 1		–	6 } 13	16 2 } 35 1
Slight complaints	5	27 8	2	10 5	7	18 9
Partial	4	22 2	2	10 5	6	16 2
Incapacity						
Due to the spinal disease back pain and possibly sinus	–	–	12	63 2	12	32 4
Due to other disease previous poliomyelitis	1	5 6	–	–	1	2 7
Dead						
Still unable to work	–	–	2	10 5	2	5 4
Not traced						
But unable to work when last seen	2	11 1	1	5 3	3	8 2
Total	18	100 0	19	100 0	37	100 0

Slight complaints were found in six patients (16 2 per cent)

General mobility was poor in 35 of the patients before treatment started it was good in 19 patients at the end of the twelve month treatment period

TABLE 34 *Interval between beginning of treatm nt by the hospital and full resumption of work in 37 patients receiving ambulatory treatment with anti tuberculosis drugs (Group B)*

Interval	Children		Adults		Cumulative total	
	Number	Per cent	Number	Per cent	Number	Per cent
No interval	2	11 1	–	–	2	5 4
Less than 3 months	–	–	–	–	2	5 4
3–6 months	1	5 6	–	–	3	8 1
6–9	6	33 3	–	–	9	24 3
9–12	2	11 1	2	10 5	13	35 1
Partial working capacity incapacity dead or not traced	7	38 9	17	89 5	37	100 0
Total	18	100 0	19	100 0	37	100 0

(d) *Kyphosis*

The clinical kyphosis after twelve months was as follows

Kyphosis group	*Number of children*	*Number of adults*
0–2	11	15
3–4	5	1

The remaining five patients had either died or could not be traced The child with a double lesion was classified as belonging to group 0–2

The changes in radiological kyphosis after twelve months were as follows

Changes	*Number of lesions*
Increase 10 –45	10
Decrease	1
No change	22
Dead or not traced	5

The 10 lesions which showed an increase represented 26 3 per cent of all 38 lesions

(e) *Complications during treatment*

The following complications developed

Complication	*Number of patients*
Tuberculosis of female pelvic organs	1
Palpable abscess	3
Sinus formation	3
Intolerance to PAS	1

(f) *Failures and relapses*

Ambulatory treatment may be considered to have failed in the eight patients who were excluded because they disappeared after the first examination failed to continue regular medication or went to another hospital (see page 73) Failure may also be considered to be the outcome in the case of 31 out of the 32 patients seen after twelve months who still had clinical and/or radiological symptoms and signs Nothing can of course be said about the three patients who were not traced after twelve months

There was a relapse in respect of back pain in one case and in respect of sinus in another

(g) *Mortality*

One patient committed suicide after three months this was discovered when a visit was paid to his home after twelve months his widow stated that the suicide was due to disappointment at not being admitted to hospital for operation The spine condition was reportedly unchanged up to death

A second patient developed fever after three months with diarrhoea accompanied by the passage of blood and died within two weeks this information was obtained from the patient s family on a visit to her home after twelve months In this case also the spine condition was reported to be unchanged up to death

4 Effect of Various Factors on Prognosis

Age had an effect on the recovery of complete working capacity as shown in Table 31 The difference between the proportion in children (61 1 per cent) and in adults (10 5 per cent) is 50 6 per cent which is more than three times the standard error for this difference (± 15 7 per cent) The groups are too small to justify further study of detail in regard to the effect of age on this feature

The effect of age on certain other features is outlined below

Feature	*Effect of age*
Recumbency	Shorter in children than in adults (see Table 30)
Interval between start of treatment and full resumption of work	Shorter in children than in adults (see Table 34)
Radiological improvement	None (6 out of 16 followed up lesions in adults 5 out of 17 in children) (see Table 33)

TABLE 34 *Interval between beginning of treatment by the hospital and full resumption of work in 37 patients receiving ambulatory treatment with antituberculosis drugs (Group B)*

Interval	Children		Adults		Cumulative total	
	Number	Per cent	Number	Per cent	Number	Per cent
No interval	2	11 1	–	–	2	5 4
Less than 3 months	–	–	–	–	2	5 4
3–6 months	1	5 6		–	3	8 1
6–9	6	33 3	–	–	9	24 3
9–12	2	11 1	2	10 5	13	35 1
Partial working capacity incapacity dead or not traced	7	38 9	17	89 5	37	100 0
Total	18	100 0	19	100 0	37	100 0

(d) *Kyphosis*

The clinical kyphosis after twelve months was as follows

Kyphosis group	*Number of children*	*Number of adults*
0–2	11	15
3–4	5	1

The remaining five patients had either died or could not be traced The child with a double lesion was classified as belonging to group 0–2

The changes in radiological kyphosis after twelve months were as follows

Changes	*Number of lesions*
Increase 10°–45°	10
Decrease	1
No change	22
Dead or not traced	5

The 10 lesions which showed an increase represented 26 3 per cent of all 38 lesions

(e) *Complications during treatment*

The following complications developed

Complication	*Number of patients*
Tuberculosis of female pelvic organs	1
Palpable abscess	3
Sinus formation	3
Intolerance to PAS	1

(f) *Failures and relapses*

Ambulatory treatment may be considered to have failed in the eight patients who were excluded because they disappeared after the first examination failed to continue regular medication or went to another hospital (see page 73) Failure may also be considered to be the outcome in the case of 31 out of the 32 patients seen after twelve months who still had clinical and/or radiological symptoms and signs Nothing can of course be said about the three patients who were not traced after twelve months

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Feature	*Effect of age*
Recumbency	Shorter in children than in adults (see Table 30)
Interval between start of treatment and full resumption of work	Shorter in children than in adults (see Table 34)
Radiological improvement	None (6 out of 16 followed up lesions in adults 5 out of 17 in children) (see Table 33)

Feature	*Effect of Age*
Fusion	More frequent in adults (5 out of 16 followed up lesions) than in children (2 out of 17 lesions) (see Table 33)
Clinical kyphosis and change in radiological kyphosis	Discussed below

The following features had no effect either on working capacity or on radiological findings *duration of symptoms region of spine involved radiological grouping pulmonary and extrapulmonary complications* It is not considered practicable to include in this presentation the data on which this statement is based

Clinical kyphosis 3–4 and increase in radiological kyphosis of 10°–45° were seen more often in children than in adults, more often in upper spinal than in lower spinal lesions and more often in lesions of the radiological groups 3–4 than the radiological groups 1–2 but the figures are too small to warrant detailed presentation

Other Groups of Patients

In addition to the findings in study groups A and B a brief account will be given in the following of certain observations on other patients which did not fall within the plan of the investigation but which are nevertheless of interest in its context

(a) *Patients in group B operated upon after twelve months*

As a consequence of persistent symptoms and signs 30 patients in group B were advised to undergo operation after twelve months of ambulatory treatment with anti tuberculosis drugs In 17 of these cases there were both clinical and radiological symptoms and signs in eight cases clinical only and in five cases radiological only Of these 30 patients 25 agreed to undergo operation They are actually a group of patients who underwent operation after a long period of pre operative medication as distinct from those comprising group A

These patients included the majority of those making up group B on whom information has already been given It will therefore be sufficient to mention that there were 13 children and 12 adults and that there were no significant differences between these and group B as a whole in respect of duration of symptoms region of the spine involved number of vertebrae affected and radiological grouping The duration of pre operative medication with INH and PAS had lasted twelve to fifteen months in 22 cases and fifteen months to eight years in three cases while the pre operative medication with SM the operation and the post operative anti tuberculosis medication were the same as for group A

The post operative observation period was about eighteen months at the end of which 24 patients were followed up and one had died

Gross pathology was found on operation in 14 cases and not found in 11 cases The findings were as follows

Pus and/or caseous material	9 cases
Granulation tissue and/or bone sand	11 cases
Bone and/or disc sequestrum	12 cases

Microbiological examination by culture gave the following results

Acid fast bacilli present	1 case
Acid fast bacilli not present	22 cases
No examination	2 cases

The results of the histological examinations were as follows

Tuberculous granulation tissue	13 cases
Chronic inflammation	2 cases
No pathological changes	10 cases

In two of the 11 cases without gross pathological changes at operation tuberculous granulation tissue was found histologically in these two cases acid fast bacilli were found in one and not in the other

The correlation between the microbiological and histological findings is shown in Table 35

TABLE 35 *Microbiological and histological findings in material removed by operation in 25 patients operated on after receiving ambulatory treatment with anti tuberculosis drugs for twelve months*

Histological findings	Microbiological findings			Total
	Acid fast bacilli		No examination	
	Present	Not present		
	Number	Number	Number	Number
Tuberculous granulation tissue	1	12	–	13
Chronic inflammation without definite evidence of tuberculosis	–	2	–	2
Bone tissue cartilage fibrous tissue	–	8	2	10
Total	1[1]	22[1]	2	25

[1] By culture

Other information with regard to these patients can be summarized as follows

Post operative recumbency	Less than one month	12 cases
	Less than three months	21 cases
Hospitalization	Within four to six weeks in 24 cases average twenty three days	

Working capacity	
Before operation	Complete working capacity … symptoms … two out of 12 …
At last follow up examination	Complete working capacity … and six out of 12 … (60 0 per cent) … had complete working … seven months … occurred[1] … capacity
Slight complaints	In seven patients … i e 28 0 per cent
Radiological results	Improvement in … 12 … adults out of 12 … (see Table 53) No change … one patient had died
Interval between operation and full resumption of work	Complete working capacity … months of operation in 11 … and four out of 12 adults … (60 0 per cent) within six … children and six adults

(b) *Patients in group B who continued ambulatory treatment … operation*

Seven patients in group B (three children four adults) … their ambulatory treatment Five were followed up after a … of observation of twenty eight to thirty four months whil… not traced Only one patient had complete and three partial … capacity One was unable to work because of sequelae from … poliomyelitis Radiological improvement was found in four … no changes in one Sinus had relapsed after two and a half years in … patient this was incidentally the only patient in group B who had been found after twelve months to be without clinical symptoms and signs and who showed radiological improvement

(c) *Patients treated by radical operation without the addition of anti tuberculosis drugs*

The author hesitated to use this method in a systematic way When the first year of investigation gave an impression however that patients operated on following only a few days pre operative medication and with a few months post operative medication with anti tuberculosis drugs apparently did as well as patients in whom medication lasted for longer periods it was considered that a limited trial was justified

[1] This patient was stated by her mother in law to have died after a short illness accompanied by bloody sputum

and would be of practical as well as of theoretical interest Careful selection of patients was essential and only those without symptoms and signs of other tuberculous manifestations could be treated in this way Furthermore anti tuberculosis drugs would be given immediately if indicated by the post operative course

The operation was performed on a group of four children and four adults The following is the relevant information

Gross pathological changes at operation	8 cases
Acid fast bacilli present by culture	6 cases
Acid fast bacilli not present by culture	2 cases
Tuberculous granulation tissue found by histological examination	7 cases
Bone tissue and cartilage found by histological examination	1 case

The immediate post operative course was characterized by persistence of back pain and in some cases by fever For this reason anti tuberculosis medication was begun in five cases In a sixth case SM was left in the wound by mistake and the parents of this patient also gave her SM for one month after discharge A seventh patient died two days after operation the cau e of death was not known and could not be discovered at autopsy Only one patient therefore received no anti tuberculosis drugs throughout the entire observation period

The condition of the patients at the follow up examination fifteen to eighteen months after the operation is summarized below

Working capacity	Complete working capacity two cases (one man re operated on after anti tuberculosis medication started and one child where SM was left in wound)
	Partial working capacity three cases (includes patient who received no anti tuberculosis drugs)
	Incapacity for work two cases
Persistent back pain	Five cases
Sinus	Healing in one out of three cases
Radiological results	Improvement none
	No change six cases
	Deterioration one case (the patient who received no anti tuberculosis medication this patient also showed radiological signs of disseminated pulmonary tuberculosis)

(d) *Patients who received no treatment*

Since not all patients advised to go elsewhere for treatment (see pages 27–28) in fact did so a group of 10 such patients (five children and

five adults) were visited after a period of twelve months these patients were chosen at random from among those living in Seoul It appeared that three of these had received some treatment while seven had remained untreated Among these entirely untreated patients five were unable to work and two had gradually become worse and died reportedly because of their spinal disease

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Since not all patients advised to go elsewhere for treatment (see pages 27–28) in fact did so a group of 10 such patients (five children and

Comparison of Results of Treatment

1. Group A and Earlier Reports
2. Group A and Group B
3. Group A and Other Groups of Patients

ally healed is difficult to make Following years of quiescence the process may flare up In the present report the term healed is therefore not used and the results of treatment were assessed on the basis of clinical and radiological findings within their limits of difference in interpretation Certain factors can be clearly measured such as body weight ESR and Hgb However these can at most indicate improvement but not healing In addition in the present investigation these factors are of limited value owing to certain practical difficulties arising from local conditions Thus while it was possible to measure the body weight on admission to the hospital ward and at the last follow up examination this could not be done during all control examinations since it was not possible to persuade patients to undress completely at the out patient clinic Furthermore the values of ESR and Hgb were probably also affected by the infestation of patients with parasites (page 99) Also while an ESR of 1–9 mm/1 hr was found in cases with florid tuberculosis of the spine more than 50 mm/1 hr could be observed in cases with no other symptoms or signs of disease

Other objective signs include the healing of a sinus the disappearance of paralysis and the normalization of the reflexes in a paraplegic patient But these apply only to patients in whom these signs were originally present and do not prove healing either Improvement in mobility and disappearance of tenderness cannot be precisely measured To the patient the disappearance of pain appears as a most important indication of healing but is difficult to assess objectively apart from the fact that some patients do not have pain

Working capacity is an important criterion of the state of health of an individual As a rule full working capacity indicates good health and when an individual becomes fully capable of working after having been temporarily incapacitated because of disease this is an indication of improved health The criterion has therefore been regarded as important in the assessment of the clinical results in the present investigation in spite of the fact that an evaluation of working capacity itself cannot be fully objective On the contrary it is affected by the patient s personality as well as by factors other than the tuberculosis of the spine It was mentioned that two patients in group A had complete working capacity before operation (see page 51) and two patients in group B also had complete working capacity before treatment started (see page 79) In the present investigation it is believed that the poor economic situation of the patients could have forced the adult patients back to work rather early on the other hand prevailing extensive unemployment would possibly ensure that any employee whose work was not completely satisfactory would be dismissed

The criteria adopted for the assessment of radiological improvement have been described on page 36 it will be remembered that such assessment is subject to differences in examination technique and to differences in the interpretation of the radiographs and that pathological changes may be present in a vertebra without this being apparent from the radiograph

The assessment of kyphosis and of differences in kyphosis by radiological examination does not give precise results The angle which appears on the film is affected by the position of the patient in relation to the direction of the radiological beam it may be different in a plain radiograph and a tomograph taken on the same day it may be difficult to determine e g in cervico dorsal lesions and in extensive lesions (Fig 14) Changes of kyphosis of less than 10° or perhaps even 15 should be regarded with caution

It must be concluded that very few strictly objective clinical and radiological criteria exist for the assessment of the results of treatment and that they cannot be expected to be present in all patients The best criteria available require the use of judgment in their application and caution must therefore be exercised in the comparison of data in different investigations

Size of the patient material and period of observation Group A included 100 patients The follow up examination of April June 1960 was made difficult by the fact that it happened to coincide with a national revolution Nevertheless 84 patients were examined while in the follow up examination of September November 1961 94 patients (94 0 per cent) were seen two were not traced and four had died

The period of observation was two to two and a half years which is adequate for the assessment of the short term results of treatment and for the detection of serious immediate complications It is not adequate to assess the long term results although an indication of what these are likely to be is given by the fact that there was little change as between twelve months and two to two and a half years after operation In addition 44 patients were examined after three to three and a half years by the author s successor in Seoul [1] and essentially the same results were found as those observed by the author after two to two and a half years It may be mentioned in this connexion that FELLANDER (1954) HODGSON & STOCK (1960) and DEBEYRE (1961) reported that they found little change after the first one or two years following radical operation It is also relevant that many reports on the usual method of treatment by radical operation in conjunction

[1] Dr H Thrap Meyer

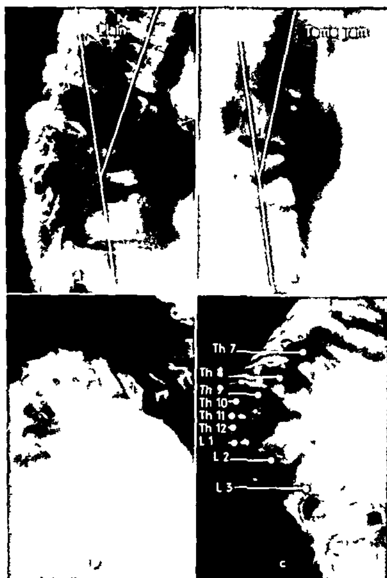


Figure 14 *The difficulty of exact assessment of radiological kyphosis*

a *The angle may vary as between a plain radiograph and a tomogram taken on the same day*

b *The axis may be difficult to distinguish in cervico dorsal lesions*

c *The axis may be difficult to distinguish in extensive lesions*

with anti tuberculosis drugs are based on periods of observation not much longer than those in the present investigation

It appeared that the size of the patient material and the proportion of patients followed up were adequate for conclusions to be drawn. The period of observation was long enough for the assessment of the short term results of treatment but caution is needed in prognosticating the long term results.

Composition of patient material and environmental conditions. In the present investigation the patient group included 42.0 per cent children. In earlier reports the percentage of children varied. FELLANDER (1954) e.g. reported 11.0 per cent under the age of 20 and KASTERT (1957) reported 12.8 per cent up to 15 years old, while HODGSON & STOCK (1960) reported 69.0 per cent up to 10 years old and KONSTAM & BLESOVSKY (1962) reported 64.2 per cent up to 12 years. Since the distribution between children and adults thus varied between the present investigation and in earlier reports, and since the prognosis in respect of working capacity in the present investigation is better for children than for adults while for kyphosis worse, it would have been of value to deal separately with children and adults. This was not possible since some of the earlier reports do not distinguish between children and adults.

It was shown in the present investigation that the region of the spine involved, the extent of the lesion (radiological grouping) and the presence of pulmonary and extrapulmonary complications had no effect on the ensuing working capacity or on the radiological findings. However, the patients in group A did not appear to differ in any important ways from those dealt with in earlier reports in respect of the region of the spine involved (see page 42). There was a difference with regard to the extent of the lesion since the average number of vertebrae affected in this investigation was 4.2, compared with 2.4–3.0 in the reports on the orthodox method of treatment (ALVIK 1949, HALLOCK & JONES 1954 and BAKALIM 1960), and 2.3–2.5 in reports on the usual method of treatment by radical operation in conjunction with anti tuberculosis drugs (FELLANDER 1954, KASTERT 1957); in one report it was 3.4 (HODGSON & STOCK 1960). The proportion of patients with 1–2 vertebrae affected was 28.0 per cent in the present investigation compared with 52.0–79.8 per cent in earlier reports. It is noted that many of these reports date back to a time when tomography was not used.

The proportion of patients with paraplegia in group A (21.0 per cent) was high as compared with most of the reported rates, 4.5–10.8 per

* — Dr. Bernhard Paus



Figure 15. *Examples of housing conditions in South Korea at the time of the investigation*

cent (ALVIK 1949, FELLANDER 1954, KASTERT 1957, CAUCHOIX *et al* 1961), while 35.0 per cent was reported by HODGSON & STOCK (1960).

The present investigation was carried out in Seoul, South Korea, which is located on about 37.5° N. The average temperature varies between 25–26 °C in the summer and −8° to −12 °C in the winter. The houses were small, overcrowded and dark. As a result of the war, people also lived at the time of the investigation in tents and shacks (Fig. 15). Windows were small and semi-transparent rice paper was often used instead of glass. People slept on mattresses on the floor and these were put away during the day when the room was used for ordinary domestic purposes. Isolation and rest at home were practically impossible. The houses were poorly heated and diseases of the upper respiratory tract were common during the cold season.

The patients were of Mongolian race and more than 90.0 per cent belonged to the poorest classes of the population. The monthly net income of a labourer was stated to be about 23 000 *huan*[1] while the minimum cost of living for an average family of 5.2 required 35 000 *huan* (TAK 1960). Unemployment was widespread, the proportion being said to be 30.0 per cent of the adult male population. A social security system was only at the planning stage.

[1] 1 000 *huan* equalled US $1.00 at the official rate of exchange in 1960.

Food consisted mainly of steamed rice with some additional vegetables and fish; meat was generally beyond the means of most of the population, while milk and milk products were practically unknown (IM 1960).

A large proportion (80.0–90.0 per cent) of the population were infested with one or more parasites, among which the most common were *Clonorchis sinensis*, *Ankylostoma duodenale*, *Ascaris lumbricoides*, *Trichuris trichiura* and *Trichostrongylus orientalis* (USAID and WHO 1962). Malnutrition caused by lack of animal protein, fats, the vitamin B group and ashes is a national malaise (SONG 1960, page 312). It is of interest in this connexion that the average weight of patients before operation was 49.5 kg (see page 54), while the average height of the Korean male is 161–169 cm (KIM KISU 1960).

Little can be said regarding the type and virulence of the tubercle bacillus in this investigation as compared with earlier reports from other parts of the world, nor regarding any possible effect of race and climate on the tuberculous process or on prognosis. It has, however, been pointed out that the morbidity of pulmonary tuberculosis in the population was high (see page 24). The proportion of cases with necrosis as shown by histological examination in group A was 64.0 per cent of the total and 86.5 per cent of those with tuberculous granulation tissue, the last figure being in agreement with those of KASTERT (1957), namely 85.66 per cent for his own material and 81.7–89.1 per cent for that of other writers. The further course in the few patients treated by radical operation without anti-tuberculosis drugs and in the few patients who remained untreated and were followed up does not suggest that tuberculosis of the spine runs a particularly favourable course in South Korea. Further, some of the earlier reports originate from countries close to South Korea: Hong Kong, Japan, Singapore (HODGSON *et al.* 1956–63, KONDO & YAMADA 1951–61, KATAYAMA *et al.* 1956, 1961, and KARLÉN 1959).

It appeared that the composition of the patient material and the environmental conditions did not place the study group in the investigation at an advantage as compared with other patient material. The high proportion of children should, however, be borne in mind.

The *results of treatment were computed* on the basis of the total number of patients in the investigation. The same procedure was used also in some earlier reports, but in others the evaluation was based on the number of surviving patients only or on the number of patients actually followed up. It is concluded, therefore, that the method of computation used does not introduce any bias in favour of the treatment under investigation.

(b) *Comparison of results of treatment*

A detailed comparison of the results obtained with the treatment under investigation with those published in earlier reports is presented in Tables 36–45 This comparison shows the following

Feature	*Comparison of group A with earlier reports*
Recumbency	Shorter in group A (see Table 36)
Hospitalization	Shorter in group A (see Table 37)
Working capacity	Findings compare favourably (see Table 38)
Slight complaints	Frequency compares favourably (see Table 39)
Recovery from paraplegia	Frequency compares favourably (see Table 40)
Radiological improvement	Frequency compares favourably (see Table 41)
Fusion	Frequency compares favourably (see Table 41)
Interval between operation and full resumption of work	*Shorter in group A (see Table 42)*
Clinical kyphosis	Findings compare favourably (see Table 43)
Change in radiological kyphosis	*Findings compare favourably (see Table 44)*
Healing of sinus	No comparison made not often discussed in earlier reports
Operative mortality	Findings compare favourably (see Table 45)

TABLE 36 *Recumbency in the present investigation (Group A) and in earlier reports estimated in Group A as interval between operation and time when patients were completely up and about but in earlier reports probably estimated as interval from beginning of treatment or operation to time when patients started to be up and about*

Group A[1]	Orthodox treatment[2]	Radical operation[3]
Less than 3 months in 43 0 per cent Less than 6 months in 71 0 per cent	13 months– 5 years	Most authors 3–8 months

[1] See Table ~
[2] See pages 10 and 12
[3] See page 16

TABLE 37 *Duration of hospitalization in the present investigation (Group A) and in earlier reports*

Group A[1]	Orthodox treatment[2]	Radical operation[3]
Up to 30 days in 57 5 per cent Up to 40 days in 71 2 per cent Up to 60 days in 88 3 per cent Average 35 days	13 months– 5 years	Most authors 4–6 months

[1] See Table 8
[2] See pages 10 and 12
[3] See page 16

TABLE 38 *Working capacity in the present investigation (Group A) and in earlier reports*

Working capacity	Group A[1]	Orthodox treatment[2]	Orthodox treatment with anti tuberculosis drugs[3]	Ambulatory treatment[4]	Radical operation[5]
	Per cent	Per cent	Per cent	Per cent	Per cent
Complete	80 0	29 1–44 0	93 0	86 0	53 3–95 7
Complete and partial	86 0	36 5–73 0	–	?	68 0–95 7

[1] See Table 10
[2] See page 11
[3] See page 12
[4] See page 12
[5] See Table 1

TABLE 39 *Slight complaints in the present investigation (Group A) and in earlier reports*

Group A[1]	Orthodox treatment[2]	Radical operation[3]
Per cent	Per cent	Per cent
34 0	14 7–73 4	11 0–32 3

[1] See page 51
[2] See page 11
[3] See page 17

TABLE 40 *Complete recovery from paraplegia in the present investigation (Group A) and in earlier reports*

Reports	Complete recovery	Total in group
	Number	Number
Group A[1]	16	21
Orthodox treatment[2]		
Alvik (1943)	10	23
Griffiths *et al* (1956)	80	141
Kaplan (1959)		
without anti tuberculosis drugs	18	31
with anti tuberculosis drugs	24	29
Ambulatory treatment[3]		
Konstam & Blesovsky (1962)		
without operation	26	28
with operation	25	28
Radical operation[4]		
Kastert (1957)	11	19
Hodgson & Stock (1960)	26	35
Cauchoix *et al* (1961)	12	22
Risko & Novoszel (1963)	10	10

[1] See Table 11
[2] See pages 11 and 12
[3] See page 13
[4] See page 17

TABLE 41 *Radiological findings in the present investigation (Group A) and in earlier reports*

Radiological findings	Group A[1]	Orthodox treatment[2]	Orthodox treatment with anti tuberculosis drugs[3]	Ambulatory treatment[4]	Radical operation[5]
	Per cent	Per cent	Per cent	Per cent	Per cent
Improvement/Healing	78 6[6]	35 0 88 0	?	?	52 0–94 0
Fusion	57 2	48 0–92 5	56 1	74 0	38 0–94 0

[1] See Table 13
[2] See page 11
[3] See page 12
[4] See page 13
[5] See Table [illegible]
[6] Computed on the basis of the total number of lesions if computed only on the basis of the lesions examined at the follow up examination and whenever interpretation of radiographs was possible the percentage would be 89 0

TABLE 42 *Interval between operation and full resumption of work in the present investigation (Group A) and the interval in earlier reports between beginning of treatment fusion operation or radical operation and resumption of work*

Interval Months	Group A[1]	Orthodox treatment[2]	Ambulatory treatment[3]	Radical operation[4]
	Per cent	Per cent	Per cent	Per cent
Less than 6	45.0	–	–	13.0
Less than 12	74.0	50.0	59.0	43.0

[1] See Table 15

[2] See page 11 In addition *Alvik* (1949) reported resumption of work within 6 months after discharge from hospital in 24.46 per cent and within 12 months in 58.16 per cent

[3] See page 13

[4] See page 19 In addition *Wilkinson* (1957) reported a period of 12 months between operation and resumption of work and *Cauchoix et al* (1961) a period of 16 months

TABLE 43 *Clinical kyphosis in Groups 3–4 in the present investigation (Group A) and Moderately large or Very large in earlier reports*

By age

		Group A[1]	Orthodox treatment[2]	
			Bierring (1934)	Alvik (1949)
Observation in years		2–2½	– 12	2–10
Children				
Total in group		42	17	22
With kyphosis	Number	18	8	13
	Per cent	42.9	47.0	59.1
Adults				
Total in group		58	59	251
With kyphosis	Number	5	10	43
	Per cent	8.6	17.0	17.1

By region of spine involved

		Group A[1]	Orthodox treatment[2]
			Alvik (1949)
Observation in years		2–2½	2–10
Upper spinal lesions			
Total in group		52	118
With kyphosis	Number	21	44
	Per cent	40.4	37.3
Lower spinal lesions			
Total in group		48	155
With kyphosis	Number	2	12
	Per cent	4.1	7.7

[1] See Figure 11 [2] See page 11

TABLE 44 *Changes in radiological kyphosis in the present investigation (Group A) and in earlier reports*

Changes	Group A[1]		Orthodox treatment[2]				Ambulatory treatment[3]		Radical operation[4]	
			Hallock & Jones (1954)		Bakalim (1960)		Konstam & Blesovsky (1962)		Cauchoix *et al* (1961)	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cen[t]
Increase between 10 and 30	18	–	20	–	7	–	59	–		–
30 or more	9	–	11	–	4	–	18	–	–	–
Increase 10 or more	27	26 2	31	39 2	11	18 6	77	37 2	–	25
Decrease	1	1 0	3	3 8	–	-	8	3 8	–	–
No change	68	66 0	45	57 0	48	81 4	120	58 0	–	74
Patients dead or not traced	7	6 8	–	–	–	–	2	1 0	–	1
Total number of lesions	103	100 0	79	100 0	59	100 0	207	100 0	211	100

[1] See Table 16
[2] See pages 11 and 12
[3] See page 13 The numbers are approximations and have been estimated on the basis of these investigators histogram
[4] See page 19

TABLE 45 *Operative mortality in the present investigation (Group A) and in earlier reports*

Group A[1]	Radical operation[2]
Per cent	Per cent
1 0	0 0-9 9

[1] See page 61
[2] See page 19

Group A and Group B

(a) *Basis of comparison*

The criteria used for the assessment of the results of treatment were the same for groups A and B The assessment was made personally by the author in both instances The patients were drawn from the same population with the same environmental conditions and were treated in the same hospital during the same period The size of the groups and the proportion of followed up cases were as follows

Group	*Original number of patients*	*Followed up patients*	
		Number	*Per cent*
A	100	94	94 0
B	37	32	86 5

Circumstances prevented the enlargement of group B as already discussed the proportion of cases followed up is considered to be ade quate particularly since information about the condition before death was available also in the 4 patients in group A and 2 patients in group B who died The period of observation was different in the two groups but it has been shown (see page 61) that the clinical findings in group A were essentially the same after twelve months and at the last follow up examination and that the radiological findings had probably changed to only a small extent

The composition of the patient materials was essentially the same in the two groups The age distribution was as follows

	Group A		*Group B*	
Age-group	*Number*	*Per cent*	*Number*	*Per cent*
Children	42	42 0	18	48 6
Adults	58	58 0	19	51 4

It has been shown that various other factors had no effect or a very uncertain effect on the results of treatment for either group These factors will nevertheless be considered in the following in order to

TABLE 44 *Changes in radiological kyphosis in the present investigation (Group A) and in earlier reports*

Changes	Group A[1]		Orthodox treatment[2]				Ambulatory treatment[3]		Radical operation[4]	
			Hallock & Jones (1954)		Bakalim (1960)		Konstam & Blesovsky (1962)		Cauchoix *et al* (1961)	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Increase between 10 and 30	18	–	20	–	7	–	59	–	–	–
30 or more	9	–	11	–	4	–	18	–	–	–
Increase 10 or more	27	26 2	31	39 2	11	18 6	77	37 2	–	25 0
Decrease	1	1 0	3	3 8	–	–	8	3 8	–	–
No change	68	66 0	45	57 0	48	81 4	120	58 0	–	74 0
Patients dead *or not traced*	7	6 8	–	–	–	–	2	1 0	–	1 0
Total number *of lesions*	103	100 0	79	100 0	59	100 0	207	100 0	211	100 0

[1] See Table 16
[2] See pages 11 and 12
[3] See page 13 The numbers are approximations and have been estimated on the basis of these investigators histogram
[4] See page 19

TABLE 45 *Operative mortality in the present investigation (Group A) and in earlier reports*

Group A[1]	Radical operation[2]
Per cent	Per cent
1 0	0 0-9 9

[1] See page 61
[2] See page 19

vertebrae affected in 20 out of the total of 23 cases. They were consequently allocated to group A (see page 27).

It is concluded that a comparison of the results of treatment in groups A and B is justified and that any differences found should mainly be due to differences in the treatment. These differences consisted in the use of radical operation in group A with accompanying hospitalization of an average duration of thirty five days, medication with SM during this period and with training and instruction in exercises. The use of other anti tuberculosis drugs and the omission of enforced recumbency and of immobilization were the same in both groups. It would have been of interest to limit the difference in treatment solely to the inclusion or omission of the operation but time and ward capacity did not permit the hospitalization of group B patients even for thirty five days.

(b) *Comparison of results of treatment*

A detailed comparison of some of the results of treatment in group A and in group B is presented in Tables 46–51. The comparison shows the following:

Feature	*Comparison of group A with group B*
Recumbency	Shorter in group A (see Table 46)
Working capacity	Better in group A (see Table 47). The difference in complete working capacity among children (34.1 per cent) and adults (58.5 per cent) is significant, being more than three times the standard error for these differences (± 10.0 and ± 13.1 per cent respectively)
Back pain disappeared, mobility improved, tenderness ceased, sinus healed	More often in group A (see Table 48) but observations of limited value as criteria for comparison
Recovery from paraplegia	No comparison justified as group B included only two cases (see Table 48)
Radiological improvement	More often in group A (see Table 49); the difference (49.7 per cent) is significant, being more than three times the standard error for this difference (± 9.0 per cent)
Fusion	More often in group A (see Table 49); the difference (38.8 per cent) is significant, being more than three times the standard error for this difference (± 9.5 per cent)
Interval between operation or beginning of treatment and full resumption of work	Shorter in group A (see Table 50)

Feature	*Comparison of group A with group B*
Change in radiological kyphosis	The same (see Table 51) group B too small for division of patients into children and adults and of lesions into upper spinal and lower spinal the distributions were however nearly the same in group A and in group B

TABLE 46 *Recumbency in Group A and Group B*

Recumbency	Group A[1]		Group B[2]	
	Number	Per cent	Number	Per cent
Less than 3 months	43	43 0	2	5 4
Less than 6 months	71	71 0	5	13 5
Less than 12 months	89	89 0	22	59 5

[1] See Table 7
[2] See Table 30

TABLE 47 *Working capacity in Group A and Group B*

Working capacity	*Children*				*Adults*			
	Group A[1]		Group B[2]		Group A[1]		Group B[2]	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Complete	40	95 2	11	61 1	40	69 0	2	10 5
Partial	–	–	4	22 2	6	10 3	2	10 5
Total	40	95 2	15	83 3	46	79 3	4	21 0

[1] See Table 10
[2] See Table 31

TABLE 48 *Back pain general mobility tenderness healing of sinus and recovery from paraplegia in Group A and Group B*

Feature	Group A[1]		Group B[2]	
	Number	Per cent	Number	Per cent
No back pain	94	94 0	12	32 4
General mobility good	84	84 0	19	51 3
No tenderness[3]	72	87 8	14	46 7
Sinus healed	19	90 5	7	53 8
Complete recovery from paraplegia	16	76 2	2	100 0

[1] See pages 50–54
[2] See pages 78–80
[3] Percentages computed on the basis of patients examined for tenderness

TABLE 49 *Radiological findings in Group A and Group B*

Findings	Group A[1]		Group B[2]	
	Number	Per cent	Number	Per cent
Improvement	81	78 6	11	28 9
No change	9	8 7	15	39 4
Deterioration	1	1 0	7	18 4
Interpretation not possible patients dead or not traced	12	11 7	5	13 3
Total number of lesions	103	100 0	38	100 0
Fusion	59	57 2	7	18 4

[1] See Table 13
[2] See Table 33

TABLE 50 *Interval between operation in Group A and between beginning of treatment by hospital in Group B and full resumption of work*

Interval Months	Children				Adults			
	Group A[1]		Group B[2]		Group A[1]		Group B[2]	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Less than 3	13	31 0	2	11 1	–	3 4	–	–
Less than 6	32	76 2	3	16 7	13	22 4	–	–

[1] See Table 15
[2] See Table 34

TABLE 51 *Changes in radiological kyphosis in Group A and Group B*

Changes	Group A[1]		Group B	
	Number	Per cent	Number	Per cent
Increase 10° or more	27	26 2	10	26 3
Decrease	1	1 0	1	2 6
No change	68	66 0	22	57 8
Patients dead or not traced	7	6 8	5	13 3
Total number of lesions	103	100 0	38	100 0

[1] See Table 16
[2] See page 82

The difference in working capacity between group A and group B is significant both in children and in adults (see above) when related to complete working capacity only If patients with partial working capacity are included the difference is reduced in the case of children (see Table 47) to 11 9 per cent This is insignificant (being slightly more than the standard error of difference ±7 8 per cent) The difference remains significant in the case of adults at 58 3 per cent (more than three times the standard error for this difference ±12 6 per cent)

The number of patients who failed to complete treatment according to plan was slightly greater in group B than in group A eight patients had to be excluded from group B (see page 73) while five disappeared after three to six months i e a total of 13 patients out of the original 45 In group A 18 patients out of 100 failed to complete the planned twelve months of post operative medication (see page 46) It is important to note that patients in group A who failed to complete treatment did so because of the disappearance of symptoms those in group B might have failed for the same reason in one case but probably not in the other cases

Group A and Other Groups of Patients

The 25 patients in group B who were operated on after twelve months treatment with anti-tuberculosis drugs did not differ essentially in composition from the entire group. There were thus no essential differences as compared with group A either. The pre-operative medication with SM, the operations and the post-operative anti-tuberculosis medication were the same in the two groups, the only difference in treatment being that the pre-operative medication with INH and PAS had lasted longer in group A.

At the follow-up examination the working capacity and the radiological findings were the same for the two groups, as shown by Tables 52 and 53 respectively. Slight complaints were found with the same frequency, while the post-operative recumbency, the hospitalization and the interval between operation and full resumption of work were all shorter for the group of 25 patients.

The remaining three groups of patients were too small to justify any comparison.

TABLE 52. *Working capacity in Group A and in 25 patients operated on after receiving ambulatory treatment with anti-tuberculosis drugs for twelve months*

Working capacity	*Children*				*Adults*			
	Group A[1]		25 patients[2]		Group A[1]		25 patients[2]	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Complete	40	95.2	13	100.0	40	69.0	6	50.0
Partial	–	–		–	6	10.3	2	16.7
Incapacity, dead or not traced for examination	2	4.8		–	12	20.7	4	33.3
Total	42	100.0	13	100.0	58	100.0	12	100.0

[1] See Table 10
[2] See page 87

TABLE 53 *Radiological improvement in Group A and in 25 patients operated on after receiving ambulatory treatment with anti tuberculosis drugs for twelve months*

Group A[1]		25 patients[2]	
Number	Per cent	Number	Per cent
81	78 6	22	88 0

[1] See Table 13
[2] See page 87

Discussion

(a) *Justification of the treatment under investigation*

Practicability It was found possible to carry out the proposed anti tuberculosis medication according to plan both with regard to types of drug and to doses except in a few cases where there was intolerance to PAS and SM The duration of pre-operative medication was planned to be left to chance and was generally determined by the time that the patient had to wait before a bed became available in the ward Post-operative medication did not always follow the plan it was discontinued prematurely by 18 patients (18 0 per cent) because of the absence of symptoms and prolonged in the case of 39 patients (39 0 per cent) In most of these cases the doctor at the out patient clinic gave new supplies of drugs simply out of habit

Examination for PAS in the urine showed that nearly 90 0 per cent of the ambulatory patients were taking the prescribed PAS (see page 46) This is in accordance with the findings of WESSEL AAS (1960) at the same hospital and during the same period in 201 tests on ambulatory patients suffering from pulmonary tuberculosis 73 7 per cent positive 7 4 per cent weak (i e PAS not taken for the last 24–48 hours) and 18 9 per cent negative He classified as negative those patients who stated that their supply of PAS was exhausted while eight such patients were classified as positive in the present investigation

It was possible to carry out the operation according to plan in respect of both time and technique except in a few cases where temporary postponement was necessary owing to intercurrent attacks of malaria colds measles etc It was not possible to determine the extent to which an elimination of the lesion was achieved but 11 patients required re operation

Enforced recumbency was omitted as planned and patients got up as much and as early as they wished, even only one to two days after operation Immobilization was also omitted

Hospitalization was reduced to an average of thirty five days in accordance with the period of four to six weeks planned it was within the planned period in over 70 0 per cent of cases in spite of additional operations for extraspinal tuberculosis of bones and joints treatment for pulmonary tuberculosis etc

Comparison of results of treatment with those published in earlier reports Working capacity frequency of slight complaints recovery from paraplegia radiological findings and operative mortality were all found to compare favourably with the findings published in earlier reports (see page 100) but caution is necessary in prognosticating the long term results of treatment Clinical kyphosis and increase in radiological kyphosis were similar to the findings in earlier studies but it should be recalled that (i) the kyphosis may later increase in growing children and (ii) the kyphosis was very seldom discussed in earlier reports in relation to the age of the patients or the region of the spine involved However it appears that the important factors in regard to kyphosis are the age of the patient the region of the spine involved and the extent of the lesion (see page 70) On the other hand it appears to be of no importance from the point of view of kyphosis whether the diseased material is eliminated by surgery or by the human organism s own forces nor does early ambulation appear to have any effect

The time factor was markedly reduced in the present investigation including the duration of recumbency the hospitalization and the interval between the operation and full resumption of work One reason may be that the operation removes the diseased material in the lesion which without operation the organism must resorb encapsulate or discharge through a sinus all these processes take time An additional reason may be that patients were not exposed to the adverse side effects of recumbency or immobilization for as long as in other forms of treatment

(b) *Effect of various factors on prognosis*

Operation The working capacity was better the radiological improvement and fusion were found more frequently in group A than in group B (see pages 107–108) and there was an over all saving of time The reason for this was most probably the operation with its removal of diseased material but an effect of the hospitalization and the addition of SM cannot be excluded

Age was the main factor besides operation which affected the prognosis (see page 63) children had complete working capacity more often

than adults, they had slight complaints less frequently and the interval between operation and full resumption of work was shorter than among adults No difference in working capacity could be found by any further breakdown into age groups (see Table 17) This indicates that the growing spine has a better capacity for recovery than the fully grown thereafter an age difference had no effect on this capacity within the limits of the age groups investigated namely $1\frac{1}{2}$ to 58 years This theory is supported by the fact that in group B also children had better working capacity than adults

On the other hand there was no effect of age on the more objective signs of healing recovery from paraplegia healing of sinus occurrence of complications during treatment and radiological improvement (see page 63) Thus the effect on the prognosis may be more apparent than real and merely illustrate the difference in the character of work for children and adults in children short periods of intense exertion normally alternate with periods of rest while in adults exertion is usually continuous over long periods

While age had no effect on the frequency of radiological improvement it did affect the type of improvement adults improved more frequently by fusion (see page 63) it may be deduced that children improved more by normalization of structure sharpening of contours and filling in of defects This difference was seen in both upper and lower spinal lesions

Duration of symptoms and radiological grouping It may at first sight seem remarkable that these factors affect the results to such a small degree One reason may be that the number of patients with a history of less than six months or with a lesion in radiological group I was too small for any possible difference in prognosis to be brought out A further reason may be that once the diseased material is removed by surgery it is the completeness of the removal which is important and not the time for which this material has been present or its amount

The fact that *pulmonary and extrapulmonary complications* had no harmful effect on the prognosis for working capacity has also been reported by FELLANDER (1954) using drugs and radical operation on the other hand ALVIK (1949) found with orthodox treatment that the prognosis was worse when they were present This difference may be due to the effect of the anti tuberculous drugs or to the operative removal of the diseased material which subjects the organism to less strain than in the case of resorption and encapsulation etc

Anti tuberculosis medication No effect was demonstrated of previous medication but the number of patients may possibly have been

too small for such an effect to be brought out The fact that apparently inadequate previous medication produced no harmful effects may be connected with the seeming rareness of the development of resistance by the tubercle bacilli to anti tuberculosis drugs in cases of tuber culosis of the spine As mentioned on page 29 it was possible to carry out tests at the hospital for the detection of drug resistance only from the spring of 1960 onwards at which time the whole of group A had been operated on When tests were made for one of the 25 patients from group B who were operated on after twelve months and for five of the eight patients operated on without any pre operative anti tuberculosis medication resistance to INH PAS and SM combined was not found in any of these six cases Examination of the next group of patients treated by the same methods as those used for group A showed resistance to all three drugs in one case out of 25 (KALBAK 1961) There is no reason to believe that any difference in resistance would have been found in group A

The rareness of drug resistance in patients with tuberculosis of the spine has also been reported by other authors (see page 20) It is in contrast to the findings in patients with pulmonary tubercu losis WESSEL AAS (1961) at the same hospital and during the same period found that about one fifth of such patients were resistant or moderately resistant to all three drugs

The effect of the duration of pre-operative medication could be studied in three groups of patients (i) the eight patients who were operated on without any pre operative anti tuberculosis medication (ii) group A where pre operative medication was given for less than six months in 88 0 per cent of the patients (iii) the 25 patients from group B who were operated on after a medication period of at least twelve months Comparison of the findings shows that an increase in the pre-operative medication period is accompanied by a reduction in the number with gross pathological changes at operation and the finding of acid fact bacilli by microbiological examination and of tuber culous granulation tissue by histological examination (Table 54)

Working capacity and radiological findings were the same whether the pre-operative medication period was less than one month one to six months or twelve months and more (Table 55) The biggest difference in the Table is the difference in radiological improvement as between less than one month s medication (74 2 per cent) and twelve months and more (88 0 per cent) this difference is 13 8 per cent but is still insignificant (being slightly more than the standard error of difference = 10 7 per cent) Post operative recumbency hospitalization and the interval between operation and full resumption

TABLE 54 *Gross pathological changes at operation, acid-fast bacilli present on microbiological examination and tuberculous granulation tissue found by histological examination in material removed by operation (i) in 8 patients operated on without anti-tuberculosis drugs, (ii) in Group A with relatively short pre-operative medication and (iii) in 25 patients operated on after receiving ambulatory treatment with anti-tuberculosis drugs for twelve months*

Condition	8 patients[1]	Group A[2]	25 patients[3]
Gross pathological changes	8 out of 8	99 out of 100	14 out of 25
Acid-fast bacilli present	6 out of 8	53 out of 93[4]	1 out of 23[4]
Tuberculous granulation tissue present	7 out of 8	74 out of 98[4]	13 out of 25

[1] See page 88
[2] See page 48 and Table 9
[3] See pages 85–86
[4] Examination not carried out in remaining cases

TABLE 55 *Duration of pre-operative medication with anti-tuberculosis drugs, complete working capacity and radiological improvement*

Findings	Group A[1]				25 patients from Group B[2]	
	Less than 1 month		1–6 months		*12 months or more*	
	Number	Per cent	Number	Per cent	Number	Per cent
Complete working capacity	22	73.3	47	81.0	19	76.0
Radiological improvement	23	74.2	46	78.0	22	88.0

[1] See Tables 25 and 26
[2] See page 87

of work were all shorter with a pre-operative medication period of twelve months and more (see pages 86–87) but total recumbency and total time for resumption of work were shorter for group A.

(There was a marked difference between the results of treatment for four patients in group A with a total medication period limited to two to four months, all of whom recovered complete working capacity, and six of the patients who were operated on without pre-operative anti-tuberculosis medication although they were subsequently given INH and PAS for thirteen to sixteen months before the last follow-up examination. The number of patients in these two categories is too small for any conclusions to be reached, but the consistency of the findings is indicative. A possible explanation is that the timing of the

anti tuberculosis medication in relation to the operation and/or the addition of SM are of greater importance than the duration of medication as such)

(c) *Choice of operation for children*

Complete and partial working capacity were found in 40 out of 42 children in group A and in 15 out of 18 children in group B It was pointed out (see page 110) that this difference is insignificant It may therefore be asked whether any advantage is gained by performing the operation on children The following considerations favour operation

(i) Complete working capacity was found significantly more often among children in group A than among children in group B (see page 107) (ii) complete working capacity with no clinical symptoms and signs except possibly kyphosis was found in 76 1 per cent of children in group A (see Table 10) and in 33 3 per cent in children in group B (see Table 31) The difference 42 8 per cent is significant (being more than three times the standard error of difference ± 13 6 per cent) (iii) radiological improvement was found in 73 8 per cent of children in group A (see Table 13) and in 26 3 per cent of children in group B (see Table 33) The difference 47 5 per cent is significant (being more than three times the standard error of difference, which is ± 13 6 per cent in this case also) (iv) when 13 children were operated on after twelve months medication with anti tuberculosis drugs acid fast bacilli were still found in the material removed in one case of the 12 children where this examination was done (see page 86) and tuberculous granulation tissue was found in four cases there were no clinical or radiological findings which distinguished these children from those where acid fast bacilli and tuberculous granulation tissue were not found

The considerations against operation are (i) the insignificant difference in ensuing complete and partial working capacity among the children in group A and group B (ii) no acid fast bacilli were cultured in 11 of the 12 children operated on and examined for tubercle bacilli and tuberculous granulation tissue was not found in nine of the 13 children Indeed in five of the 13 children operated on after twelve months medication there were no gross pathological changes on operation — apart from small amounts of granulation tissue in one case — nor could acid fast bacilli be cultured and histological examination showed only bone tissue cartilage and fibrous tissue (iii) It will be recalled that in group B the anti tuberculosis medication lasted only twelve months it was carried out under

ambulatory conditions and was restricted to INH and PAS. Better results might perhaps have been obtained if the treatment had lasted for a longer period, if the children had been hospitalized and if SM had been administered in addition to INH and PAS.

There are thus important considerations for and against operation in children and the matter cannot be decided on the basis of the present investigation.

Conclusions

1 The treatment for tuberculosis of the spine with anti tuberculosis drugs in conjunction with radical operation without enforced recumbency and immobilization and with hospitalization for as short a period as four to six weeks in a general hospital proved practicable except in very few cases The two to two and a half years results of this treatment compared favourably with those obtained with the usual treatment methods, as published in earlier reports by other investigators Nothing can be said about long term results The time factor was reduced

2 The results of this treatment probably depended on the combined effect of the anti tuberculosis drugs (INH PAS SM) and the operation they were less satisfactory following treatment with the drugs alone a few observations indicated that they were also less satisfactory with operation alone

3 Age affected the prognosis children attained better working capacity than adults following treatment slight complaints were less frequent among children the recumbency was shorter, and there was also a shorter interval between operation and full resumption of work than in the adults This effect of age may only be apparent and illustrate differences in the character of work in children and adults and in information on subjective complaints

4 Age had no effect on the frequency of recovery from paraplegia healing of sinus and occurrence of complications during treatment however this conclusion is based on small groups of patients

5 Age affected the type but not the frequency of radiological improvement following treatment children improved more often by normalization of structure sharpening of contours and filling in of defects adults improved more by fusion

6 Prolongation of pre operative medication with anti tuberculosis drugs from less than one month to twelve months and more reduced

the number of cases found on operation to have gross pathological changes there were also fewer patients with acid fast bacilli found by *microbiological examination* and *fewer* with tuberculous granulation tissue observed by histological examination in the material *removed by operation*

7 Prolongation of pre operative medication with anti tuberculosis drugs *from less than one month to one to six months or to twelve* months and more appeared to have no effect on the results of treatment (a few observations indicated that it was important that the medication should be started before the operation was performed) No conclusions could be reached on the optimal duration of the post operative medication

8 Prolonged observation from twelve months to two and a half years the duration of symptoms before operation the region of the spine involved radiological grouping (i e the extent of the lesion) and the presence or absence of pulmonary and extrapulmonary complications had no effect or no significant effect on working capacity and radiological improvement

9 Age the region of the spine involved and the extent of the lesion affected the clinical kyphosis and the increase in radiological kyphosis early ambulation had no effect on it

10 Radical operation appeared to be indicated in all cases with florid tuberculosis of the spine in the age range 17 months to 58 years nothing can be said about older patients as they were not represented in the patient material investigated Patients who are in a hopeless condition because of other diseases may be exceptions

11 Children possibly may also be exceptions to this last statement since ensuing working capacity in children appeared to be approximately the same using ambulatory treatment with INH and PAS without operation Should circumstances not permit hospitalization and operation of all patients adults should therefore have priority

12 Pulmonary tuberculosis is no contra indication for operation and the condition usually improved during the period of observation

Summary

An investigation was planned to study whether enforced recumbency, immobilization and hospitalization for more than four to six weeks in specialized hospitals for bone and joint tuberculosis could be omitted in the treatment for tuberculosis of the spine by anti-tuberculosis drugs in conjunction with radical operation. The plan involved the treatment of a group of patients (group A) in the manner suggested and their follow up by regular clinical and radiological control examinations every two to three months over a period of two to two and a half years, the findings to be compared with the results obtained by usual forms of treatment for tuberculosis of the spine. The studies took place at the National Medical Center in Korea, Seoul, South Korea. Findings published in reports by previous investigators were to be used for comparison since time and bed capacity made it impossible to apply previous methods of treatment to any control groups of patients at the same time.

Should the findings in the planned investigation be in the affirmative, it was envisaged also to study the effect on prognosis of various factors. To study the actual effect of the anti-tuberculosis drugs alone, it was planned to treat another group of patients (group B) in the same way as group A but without operation. The limited time available for the investigation made it necessary to confine the treatment of this group to twelve months before the follow up examinations.

Group A consisted of 100 patients with ages ranging from 17 months to 58 years. They were treated with isoniazid and para-aminosalicylic acid throughout the treatment period, with the addition of streptomycin during hospitalization. They were admitted for operation as soon as the bed capacity of the hospital permitted it and the operation was carried out as soon as the necessary examinations had been completed. In practice 30.0 per cent of the patients were thus operated on within one month after medication with anti-tuberculosis

drugs was commenced and 54 0 per cent within two months Hospitalization lasted thirty five days on the average more than 70 0 per cent of the patients were hospitalized forty days or less

Patients were allowed to get up as soon and as much as they wanted even on the day after the operation *Thus 10 0 per cent of the patients* were completely up and about within one month of the operation *and 43 0 per cent within three months Patients were not immobilized* and had active exercises

The aim of the operation was to remove diseased material as completely as possible Bone grafts posterior fusion operation and post operative local instillation of anti tuberculosis drugs were not used

The follow up examination after two to two and a half years included 94 of the original 100 patients in the group Two patients could not be located and four had died Complete working capacity was found in 80 0 per cent of the patients (40 children 40 adults) The patients originally had 103 lesions (three patients had double lesions) radiological improvement was found in 78 6 per cent of the *original number of lesions or 89 0 per cent of 91 lesions examined* at the last follow up and where interpretation of the radiographs was possible Recovery *from paraplegia* was observed in 16 out of 21 cases even where this condition had lasted for as long as five years The interval between operation and full resumption of work was less than three months in 45 0 per cent and less than twelve months in 74 0 per cent of the cases

Complications were of minor importance except in two cases of surgical damage to the cord both the latter patients were paraplegic before operation and one of them died after five months The operative mortality may therefore be said to be 1 0 per cent Pe operations were *necessary in 11 cases*

The operation had a definite effect on prognosis better results were obtained with anti tuberculosis drugs in conjunction with operation than with anti tuberculosis drugs alone according to the findings in group B This group was originally intended to include 45 patients but eight had to be excluded for various reasons Thus 37 patients ranging from two to 58 years of age underwent ambulatory treatment with isoniazid and para aminosalicylic acid for twelve months without enforced recumbency or immobilization After twelve *months 32 patients with originally 33 lesions were followed up* while three could not be traced and two had died Complete working capacity was observed in 35 1 per cent of the patients *and radiological* improvement in 28 9 per cent of the lesions The interval between the time when treatment was started by the hospital and full resump

tion of work was in no case less than three months but two patients (5 4 per cent) were already able to work before treatment was started

Age affected some of the clinical findings in group A final working capacity was better in children than in adults the frequency of slight complaints was lower in children, and the interval between operation and full resumption of work was shorter in children than in adults This may be due mainly to the different character of work as between children and adults, and differences in complaining since no effect of age was observed on the more objective findings recovery from paraplegia healing of sinus and occurrence of complications during treatment Neither was any effect on the frequency of radiological improvement observed But the type of improvement was affected since children improved more often by normalization of bone structure sharpening of contours and filling in of defects while adults improved more by fusion

Age had the same effect on working capacity in group B as in group A

Prolongation of observation time from twelve months up to two and a half years the duration of symptoms the region of the spine involved the extent of the lesion and the presence of pulmonary and extrapulmonary complications had insignificant effect or no effect at all on working capacity and radiological improvement The results were not affected by the increase of pre operative medication with anti tuberculosis drugs ranging from less than one month to twelve months and longer Twenty five patients in group B were operated on after such a period Gross pathological changes were found less frequently than in group A where the duration of the pre operative medication with anti tuberculosis drugs was shorter The number of patients with acid fast bacilli and tuberculous granulation tissue in material removed by operation was smaller than in group A Hospitalization was shorter than in group A with an average of twenty three days The follow up examination one and a half years after the operation included 24 patients one had died Complete working capacity was found in 60 0 per cent of the patients and radiological improvement in 88 0 per cent i e approximately the same findings as in group A

Clinical kyphosis and increase in radiological kyphosis was affected by the age of the patient by the region of the spine involved and by the extent of the lesion Early ambulation had no such effect

The conditions are discussed permitting a comparison between the results of the treatment method used for group A and methods published by previous investigators These conditions are also dis

cussed as between *group A and group B* in the present investigation and it is concluded that such comparisons are justified. They show that the two to two and a half years results observed in this investigation compare favourably with the results obtained by the usual methods of treatment. Furthermore the results obtained in group A were better than those obtained in group B.

It is concluded that the treatment under investigation is practicable and is justified. Operation appears indicated in all patients with florid disease with the exception of those in a hopeless condition due to other diseases. Information is provided in this investigation regarding patients in the age range 17 months to 58 years only however. If circumstances do not permit hospitalization and operation of all patients adults should be given priority. Children could be treated without hospitalization and operation and attain approximately the same working capacity.

Pulmonary tuberculosis is no contra indication for operation.

Résumé

Une enquete a ete faite sur les possibilites de renoncer dans le traitement mixte du mal de Pott par abord direct et administration de tuberculostatiques a des mesures telles que le repos obligatoire l immobilisation et une hospitalisation superieure a quatre a six semaines dans un hopital specialise en tuberculose osteo articulaire On envisageait de traiter un groupe de malades (groupe A) suivant les modalites indiquees et de les soumettre a une surveillance clinique et radiologique par des examens repetes tous les deux ou trois mois pendant une periode de deux ans a deux ans et demi en comparant les resultats a ceux des traitements habituels du mal de Pott L etude a eu lieu a «The National Medical Center» a Seoul Coree du Sud Pour les resultats temoins l auteur se proposait de les rechercher dans la litterature ne disposant ni du temps ni du nombre de lits adequat pour appliquer parallelement aux groupes temoins les traitements plus anciens

Au cas ou l enquete donnerait des resultats positifs on se proposait egalement d etudier l influence de divers facteurs sur le pronostic Afin de preciser l effet reel des seuls tuberculostatiques on envisageait de traiter un autre groupe de malades (groupe B) de la meme maniere que le groupe A a l exclusion de la chirurgie Faute de temps ce deuxieme groupe n a pu etre traite que douze mois avant les examens de controle

Le groupe A comprenait 100 malades ages de 17 mois a 58 ans Leur traitement a comporte l administration d isoniazide et de PAS du debut jusqu a la fin avec addition de streptomycine pendant l hospitalisation Leur admission en chirurgie a eu lieu des que le permettait la capacite de l hopital et l intervention a ete pratiquee aussitot apres les examens preoperatoires habituels Pratiquement 30 0 pour cent des malades ont ete ainsi operes moins d un mois apres le debut du traitement medical et 54 0 pour cent dans les deux

mois l hospitalisation a duré 35 jours en moyenne plus de 70 0 pour cent des malades ont été hospitalisés quarante jours ou moins

Les opérés ont été autorisés à se lever très tôt et à volonté parfois même dès le lendemain de l intervention Ainsi 10 0 pour cent des malades on été complètement sur pied moins d un mois après l intervention et 43 0 pour cent moins de trois mois après Les malades n ont pas eté immobilisés et ils ont pratiqué des exercices physiques

L intervention se proposait «l exérèse totale» des tissus pathologiques Il n a été pratiqué ni greffe osseuse ni arthrodèse postérieure ni instillation post opératoire *in situ* de tuberculostatiques

Sur les 100 malades du groupe A 94 ont subi un examen de controle au bout de deux ans à deux ans et demi Deux n ont pu être retrouvés et quatre étaient décédés Quatre vingt pour cent (40 enfants 40 adultes) jouissaient d une capacité de travail intégrale A l origine 103 lésions avaient été dénombrées chez ces malades (trois malades avaient des lésions doubles) 78 6 pour cent de ce lésions ont été améliorées du point de vue radiologique Ceci correspond à 89 0 pour cent pour les 91 lésions soumises au dernier examen de controle où l interprétation des clichés a été possible La guérison de la paraplégie a été constatée dans 16 cas sur 21 même lorsqu elle existait depuis cinq ans L intervalle entre l intervention et la reprise complète du travail a été inférieur à trois mois dans 45 0 pour cent des cas et inférieur à douze mois dans 74 0 pour cent

Les complications ont été mineures sauf deux cas de lésions chirurgicales de la moelle il s agissait dans les deux cas de malades déjà paraplégiques l un des deux était mort cinq mois plus tard On peut donc chiffrer la mortalité opératoire à 1 0 pour cent Une reintervention a été nécessaire dans 11 cas

L intervention a exercé une certaine influence sur le pronostic L observation des malades du groupe B a démontré que le traitement mixte médicochirurgical donnait de meilleurs résultats que la seule administration de tuberculostatiques A l origine ce groupe devait comprendre 45 malades mais 8 ont dû en être exclus pour différentes raisons Ainsi 37 malades agés de 2 à 58 ans ont été traités par l isoniazide et le PAS sans repos obligatoire ni immobilisation Après 12 mois 32 malades originellement porteurs de 33 lésions ont été réexaminés trois n ont pu être retrouvés et deux étaient décédés Trente cinq virgule un pour cent des malades avaient une capacité de travail complète et 28 9 pour cent des lésions étaient améliorées L intervalle entre le début du traitement à l hopital et la reprise totale du travail n a jamais été inférieur à trois mois mais deux malades (5 4 pour cent) étaient aptes au travail avant tout début de traitement

Dans le groupe A l age a pu parfois jouer un certain role capacite de travail meilleure chez les enfants que chez les adultes moindre fréquence de petits troubles chez les enfants, intervalle plus court chez ces derniers entre l intervention et la reprise d une activite complete Cela peut etre du surtout a la différence entre le «travail» de l enfant et celui de l adulte et a une difference des complaints car il n a été constate aucune influence de l age sur les signes objectifs tels que la guerison d une paraplegie le tarissement d une fistule et la survenue de complications pendant le traitement pas plus que sur la frequence des améliorations radiologiques Mais les modalites de ces ameliorations en ont ete affectees consistant surtout en une normalisation de la structure osseuse une accentuation des contours et un remplissage des cavites chez l enfant et plutot en fusions osseuses chez l adulte

L influence de l age sur la capacite de travail a été la meme dans les deux groupes A et B

La prolongation de la periode d observation de douze mois a deux ans et demi la duree des symptomes la localisation des lesions et leur etendue ainsi que la presence de complications pulmonaires et extra pulmonaires n ont exercé sur la capacite de travail et sur les ameliorations radiologiques que des effets insignifiants La duree du traitement medical pre operatoire par les tuberculostatiques, allant de un a douze mois et davantage a egalement ete indifferente

Vingt cinq des malades du groupe B ont ete operes apres douze mois Des alterations pathologiques manifestes ont ete moins souvent constatees a l intervention que dans le groupe A dont le traitement pre operatoire par les tuberculostatiques avait ete plus court Moins nombreux aussi par rapport au groupe A les malades ayant des bacilles acido resistants et du tissu de granulation tuberculeuse dans le materiel preleve a l intervention La duree de l hospitalisation a ete moindre dans le groupe B que dans le groupe A avec une moyenne de 23 jours pour le premier Vingt quatre malades ont ete examines un an et demi apres l operation un malade etait mort Soixante pour cent des malades avaient recupere leur entiere capacite de travail et 88 0 pour cent avaient ete améliores du point de vue radiologique constatations presque identiques a celles du groupe A

Le degre de cyphose clinique et son accentuation radiologique ont ete influences par l age du malade par la localisation des lésions et par leur etendue le lever precoce n a eu aucun effet

Les conditions on ete discutees qui permettent de comparer les resultats du traitement applique aux malades du groupe A a ceux d autres methodes deja publiees La meme discussion a egalement

porté sur la comparaison entre les groupes A et B et il a été conclu à la validité de ces comparaisons Celles ci ont montré que les résultats après deux ans à deux ans et demi de cette enquête sont comparables à ceux des méthodes habituelles de traitement En outre les résultats du groupe A ont été meilleurs que ceux du groupe B

En conclusion le traitement étudié est à la fois praticable et justifié L intervention apparaît justifié chez tous les malades atteints d une forme floride du mal de Pott à l exception de ceux dont l état est désespéré par suite d autres maladies Toutefois la présente enquête a porté seulement sur des sujets âgés de 17 mois à 58 ans Si les circonstances ne permettent pas d hospitaliser et d opérer tous les malades les adultes devraient être admis avec priorité Les enfants peuvent être traités sans hospitalisation ni intervention pour une récupération presque identique de leur capacité de travail

La tuberculose pulmonaire ne constitue pas une contre indication à l intervention

Zusammenfassung

Es wurden Untersuchungen unternommen die zeigen sollten ob auf langeres Liegen Immobilisierung und Spitalaufenthalt von mehr als 4 bis 6 Wochen in Spezialheilstatten fur Knochen und Gelenks tuberkulose bei der Behandlung von Spondylitis tuberculosa durch Tuberculostatica und operative Herdausraumung verzichtet werden konnte Die Studie betraf die Behandlung einer Gruppe von Patienten Gruppe A und deren 2-2½ jahrige Überwachung durch regelmassige klinische und rontgenologische Untersuchungen alle 2 3 Monate Die Resultate sollten mit denen der gewohnlichen Behandlungen von Spondylitis tuberculosa verglichen werden Die Studie wurde im National Medical Center in Korea Seoul Sud Korea unternommen Als Vergleichsmaterial sollten Ergebnisse herangezogen werden die in fruheren Berichten von anderen Autoren veroffentlicht worden waren da es Zeit und Bettmangel unmoglich machten Kontrollgruppen von Patienten gleichzeitig auf klassische Art zu behandeln

Fielen die Ergebnisse der Untersuchung positiv aus so sollte auch der Einfluss auf die Prognose verschiedener Faktoren untersucht werden Die Wirkung der Medikamente allein sollte bei einer anderen Gruppe von Patienten der Gruppe B erforscht werden deren Mitglieder ebenso behandelt wurden wie diejenigen der Gruppe A aber nicht operiert wurden Die Zeit war aber beschrankt und so dauerte die Behandlung der Patienten dieser Gruppe vor der Kontrolluntersuchung nur 12 Monate

Gruppe A bestand aus 100 Patienten im Alter von 17 Monaten bis 58 Jahren Sie erhielten wahrend der ganzen Behandlungszeit Isoniazid und Paraaminosalicylsaure und ausserdem Streptomycin wahrend ihrem Aufenthalt im Krankenhaus Aufgenommen wurden sie sobald Betten frei waren und die Operation erfolgte sofort nachdem alle notigen Untersuchungen ausgefuhrt worden waren Praktisch wurden auf dieser Weise 30 0 % der Patienten in den ersten 4 Wochen

nach Beginn der medikamentösen Behandlung operiert und 54 0 % im Laufe der ersten 2 Monate Die Dauer der stationären Behandlung war im Durchschnitt 35 Tage über 70 0 % der Patienten blieben 40 Tage oder kürzer im Krankenhaus

Die Patienten durften aufstehen sobald sie wollten sogar schon an dem Tag nach der Operation Auf diese Weise waren 10 0 % der Patienten nach einem Monat und 43 0 % nach 3 Monaten völlig auf den Beinen *Die Patienten wurden nicht immobilisiert und machten* aktive Bewegungsübungen

Ziel der Operation war die möglichst radikaleste Ausräumung des kranken Gewebes Knochentransplantation und postoperative Herd instillation von Tuberculostatica wurden nicht gebraucht

Die Kontrolluntersuchungen die nach 2–2½ Jahren durchgeführt wurden betrafen 94 von den anfänglich 100 Patienten der Gruppe *Zwei Patienten konnten nicht gefunden werden und 4 waren gestor* ben Bei 80 0 % der Patienten (40 Kinder 40 Erwachsene) war die Arbeitskapazität vollständig hergestellt Diese Patienten hatten zu Beginn insgesamt 103 Läsionen (3 Patienten hatten Dobbelläsionen) Die Röntgenbilder wiesen eine Besserung in 78 6 % der Initialläsionen oder 89 0 % der bei der letzten Kontrolle untersuchten Läsionen auf – soweit eine Deutung möglich war Heilung von Querschnittslähmung *wurde in 16 von 21 Fällen beobachtet sogar wenn dieser Zustand* schon 5 Jahre angedauert hatte Die Zeitspanne zwischen der Operation und kompletter Arbeitsfähigkeit war kürzer als 3 Monate in 45 0 % und kürzer als 12 Monate in 74 0 % der Fälle

Ausser in 2 Fällen von operativer Rückenmarksläsion waren die Komplikationen nicht ernsthaft beide dieser Patienten litten vor der Operation an Querschnittslähmung und einer von ihnen starb nach 5 Monaten Man kann also die operative Mortalität mit 1 0 % angeben 11 Patienten mussten reoperiert werden

Die Prognose wurde sicher durch die Operation beeinflusst die Ergebnisse waren besser bei den Patienten die Tuberculostatica bekamen und operiert wurden als bei denen die nur medikamentös *behandelt wurden wie man aus den Resultaten der Gruppe B sieht* Diese Gruppe sollte ursprünglich 45 Patienten umfassen aber 8 mussten aus verschiedenen Gründen ausgeschieden werden 37 Patienten im Alter von 2 bis 58 Jahren wurden also ambulatorisch mit Isoniazid und PAS behandelt ohne Verschärfung der Bettruhe oder Immobilisierung Nach 12 Monaten konnten 32 Patienten die insgesamt 33 Läsionen hatten einer Kontrolluntersuchung unterzogen werden 3 konnten nicht gefunden werden und 2 waren gestorben In 3, 1 % der Fälle war die Arbeitsfähigkeit wieder vollständig hergestellt und

bei 28,9% waren Besserungen des Rontgenbildes zu verzeichnen. Die Zeitspanne von Beginn der Behandlung im Krankenhaus bis zur vollstandigen Wiederaufnahme der Arbeit betrug in keinem Falle weniger als 3 Monate, aber 2 Patienten (5,4%) waren schon vor der Behandlung arbeitsfahig.

Das Alter hatte auf den klinischen Befund in Gruppe A einen gewissen Einfluss: bei Kindern war die Arbeitsfahigkeit grosser als bei Erwachsenen, auch beklagten sich Kinder weniger uber leichte subjektive Symptomen und der Zeitraum zwischen Operation und Arbeitsbeginn war bei Kindern kurzer als bei Erwachsenen. Das kann aber hauptsachlich mit dem Unterschied der «Arbeit» von Kindern und Erwachsenen zusammenhangen und mit einem Unterschied in Klagen, denn objektiv waren folgende Faktoren nicht vom Alter beeinflusst: Heilen von Querschnittslahmung, Heilen von Fisteln und Auftreten von Komplikationen wahrend der Behandlung. Auch die Anzahl der Besserungen im Rontgenbild waren dadurch nicht beeinflusst. Aber die Art der Besserung war verschieden, da es sich bei Kindern ofter um eine Normalisierung der Knochenstruktur, um eine Verscharfung der Umrisse und ein Ausfullen der Lasionen und bei Erwachsenen um Anchylose handelte.

Der Einfluss des Alters auf die Arbeitsfahigkeit war identisch in Gruppe B und Gruppe A.

Verlangerung der Beobachtungszeit *von 12 Monaten auf 2½ Jahre*. Andauer der Symptome, Hohe der betroffenen Wirbel, Grosse der Lasionen und die Existenz pulmonarer und extrapulmonarer Komplikationen hatten sehr wenig oder gar keinen Einfluss auf die Arbeitsfahigkeit und auf die rontgenologische Besserung. Die Dauer der Behandlung vor der Operation (unter einem Monat bis 12 Monate und mehr) hat die Resultate nicht beeinflusst. Funfundzwanzig Patienten der Gruppe B wurden nach 12 Monaten operiert. Makroskopisch pathologische Veranderungen waren seltener als in Gruppe A, in welcher die Vorbehandlung durch Tuberculostatica kurzer gewesen war. Die Anzahl der Patienten, bei denen die entfernten Gewebe saurefeste Bazillen und tuberkuloses Granulationsgewebe aufwiesen, war geringer als in Gruppe A. Die stationare Behandlung war kurzer als bei Gruppe A. Sie betrug im Durchschnitt 23 Tage. Die Kontrolluntersuchung 1½ Jahre nach der Operation umfasste 24 Patienten, einer war gestorben. Vollstandige Arbeitsfahigkeit wurde bei 60,0% der Patienten festgestellt und rontgenologische Besserung bei 88,0%, d. h. *die Ergebnisse waren denen der Gruppe A ungefahr gleichwertig.*

Das Alter des Patienten, die Hohe des kranken Wirbels und die Grosse des Lasion beeintrachtigten die klinische Kyphose und die

Verstarkung der rontgenologischen Kyphose Dasselbe kann von fruhzeitigen Aufstehen nicht gesagt werden

Es wird besprochen unter welchen Bedingungen die Resultate der Behandlungsmethoden von Gruppe A und jene die von anderen Autoren veroffentlicht wurden verglichen werden konnen Die Besprechung betrifft auch die Bedingungen bei Gruppe A und Gruppe B unserer Studie der Vergleich scheint gerechtfertigt Er zeigt dass die auf 2-2½ Jahren beobachteten Resultate dieser Studie sich vorteilhaft an jenen anderer Behandlungsmethoden messen konnen Ausserdem waren die bei Gruppe A erzielten Resultate besser als jene bei Gruppe B

Es wird daraus gefolgert dass die hier besprochene Behandlung moglich und gerechtfertigt ist Eine Operation ist bei allen Patienten mit florider tuberkulosen Spondylitis angezeigt ausser ihr Zustand durch andere Gebrechen hoffnungslos sei Unsere Studie gibt allerdings nur uber Patienten im Alter von 17 Monaten bis 58 Jahren Auskunft Wenn es nicht moglich ist alle Patienten im Krankenhaus aufzunehmen und zu operieren sollte Erwachsenen Prioritat zuerkannt werden Bei Kindern kann etwa die selbe Arbeitsfahigkeit durch Behandlung ausserhalb des Spitals und ohne Operation erzielt werden

Lungentuberkulose stellt keine Kontraindikation fur die Operation dar

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and the Department of Orthopaedics (Head Professor Carl Hirsch M D)
University of Gothenburg

Translated by
Klas Magnus Lindskog

Statistical advices
Per Sigurd Agrell

Printed in Sweden
ORSTADIUS BOKTRYCKERI AKTIEBOLAG
GÖTEBORG 1964

Contents

Introduction

The debate on the morphological background of low back pain has to a large extent been focussed on the lumbar intervertebral discs To expand our means of seeking conceivable pathophysiological mechanisms capable of explaining low back pain it was deemed interesting to chart morphologically other lumbar structures Accordingly the present investigation was devoted to a systematic study of morphological changes in the lumbar synovial joints in a series of spines from autopsy cases of various ages in order to answer the following questions

What is the micromorphological picture of osteoarthritis in the lumbar synovial joints?

Are there any sex differences with respect to time of onset degree and intraspinal distribution of osteoarthritic changes in the lumbar synovial joints?

Which relations exist between ostearthritic changes in the lumbar synovial joints and aging?

Are there any differences in degree of the osteoarthritic changes between ipsiarticular joint facets ipsisegmental joints and segments in the lumbar spine?

What intrasegmental and intersegmental frequency differences and intercurrences of osteoarthritis in synovial joints disc degeneration and marginal vertebral osteophytes exist in the lumbar spine?

CHAPTER 1

Survey of the Literature

The Synovial Joints of the Lumbar Spine

*Gross Anatomy**

The synovial joints of the spine are situated between the articular processes of adjacent vertebral arches Within the lumbar spine the inferior articular processes have convex and the superior articular processes concave articulating surfaces in the horizontal plane where therefore the joint space describes part of the surface of a cylinder whose axis passes near the tip of the spinous process (Fick 1904) From the craniocaudal aspect the articular surfaces are approximately flat Osteometric studies have shown that the inclination of the articular surface in the horizontal plane is such that the joint space on the L_{1-2} level forms an angle of about 45° with the sagittal plane and assumes an increasingly frontal attitude farther caudad until it roughly coincides with the frontal plane on the L_5–S_1 level (Farkas 1941 Jonck 1961) On each level however the range of nomal variation in the inclination of the articular surface is fairly wide (Fig 1) especially in the segments L_{4-5} and L_5–S_1 where one commonly distinguishes between frontal and sagittal inclinations (Brailsford 1929) According to Davis (1955) the inferior articular processes clutch around the superior articular processes rather often in the L_{1-2} segment forming a mortice joint In the horizontal plane the articular surfaces form an angle of around 90° with a plane through the long axis of the pedicle of the vertebral arch (Junghanns 1931)

The cartilage covering the joint facet is thickest — about 2 mm — towards the centre of the joint (Fick 1904) The cartilage surface is smooth glistening and greyish white in fresh autopsy specimens The margins of the cartilage often exhibits small indentations into which small fringes from the synovial membrane insinuate themselves (Guntz 1934) The joint space extends ventrally as far as ligamentum flavum which

* Where no source is specified this description is based on statements in standard anatomy textbooks (Henle 1855 Rauber Kopsch 1955 Gray 1962)

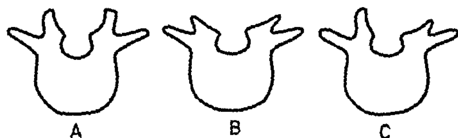


Fig 1 Typical variants in joint facet inclination A Sagittal B Frontal and C Asymmetric inclination

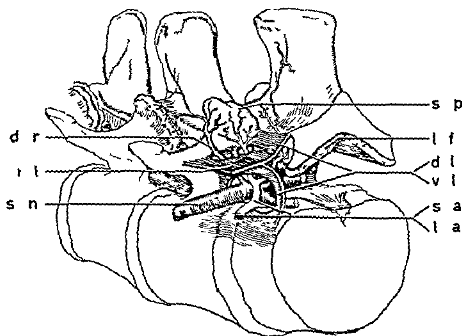


Fig 2 Topographic relations of lumbar synovial joints s p = Superior articular process l f = Ligamentum flavum i l = Intertransversal ligament d l and v l = dorsal and ventral strata of intertransversal ligament s n = Spinal nerve d r = Dorsal ramification of spinal nerve l a = Lumbar artery s a = Arterial branch to synovial joint

replaces the fibrous layer of a true joint capsule because the synovial membrane is in direct contact with it The fibrous capsule is very thick in the dorsal portions of the joint (Guntz 1934) and its outermost fibers are intimately interwoven with the multifidus muscle s insertion on the mamillary process of the vertebra (Lewin Moffet and Vidik 1962) In the cranial and caudal ends of the joint the fibrous capsule attaches a few millimetres farther beyond the osteochondral border than it does elsewhere This gives rise to pocket like widenings of the joint space These pockets are the site of a fat pad about the size of a grain of rice and coated with synovial tissue having numerous synovial fringes (Tondury, 1940 Dorr 1958) The fat pad in the superior pocket is continuous with the adipose tissue ringing the spinal nerve in the intervertebral foramen (Tondury 1940) while in the inferior pocket it is continuous with the adipose tissue between the multifidus muscle and the dorsal aspect of the lamina of the vertebral arch (Lewin Moffet and Vidik 1962)

The lumbar synovial joints are supplied with blood from the lumbar artery which after passing through the intervertebral foramen gives off a branch piercing the dorsal half of the intertransverse ligament and then giving off twigs to the joint capsule and neighbouring structures (Lewin Moffet and Vidik 1962)

The lumbar synovial joints are innervated by direct offshoots from the spinal nerve (Fick 1904 Lazorthes and Baubert 1956 Pedersen Blunck and Gardner, 1956) As one would expect from their embryonic development (Sensening 1949) the innervation of these joints is bisegmental (Stillwell 1956 Lewin Moffet and Vidik 1962) in the sense that the nerve branch on each level supplies the lateral portion (superior articular process) of that joint and the medial portion (inferior articular process) of the joint caudal thereto (Fig 2)

Microscopic Anatomy

The writer has failed to find in the literature on the anatomy of the spine any description of the microscopic appearance of the articular cartilage and subchondral bone of the intervertebral synovial joints under normal conditions But several authors have studied the micromorphology of the joint capsule in the lumbar region The fibrous layer of the capsule of the lumbar synovial joints includes thick bundles of fibres from ligamentum flavum These bundles are particularly abundant near the superior and inferior ends of the joint (Keller, 1953)

The synovial membrane in the superior and inferior ends of the joint forms a multiplicity of small villi and as a rule a larger fringe Meniscoid formations have been reported too (Zaccheo and Reale 1956 Dorr, 1958) The latter arise from the fibrous capsule and intrude a millimetre or so

between the articular surfaces These meniscoid formations may be up to about two millimetres thick next to the capsule (Zaccheo and Reale 1956) They are composed of fibrous connective tissue poor in vessels and with round or oval cells in clusters of 3 or 4 lodged in its meshes (Dorr, 1958)

The dorsocaudal portion of the joint capsule is innervated by fibres from the dorsal branch of the spinal nerve (Stillwell, 1956 Pedersen, Blunck and Gardner 1956) The complete triad of nerve endings — free fibres complex endings without a capsule and endings with small capsules — have been demonstrated in supravitally stained synovial—joint capsules, surgically removed from the lumbar spine (Hirsch Ingelmark and Miller 1963)

Function

The main function of the synovial joints is presumably to guide and stabilize flexion and extension movements (Fick, 1904) The articular surfaces slide upon one another in craniocaudal direction in flexion and extension of the lumbar spine the tip of the superior articular process in the former case receding from and in the latter approaching the inferior notch of the overlying vertebra (Dittmar, 1930 1931) Roentgenographic studies of the range of lumbar spine mobility indicate that in flexion and extension the synovial joints on the L_{4-5} and L_5—S_1 levels have the greatest range of movement (Bakke 1931 Dittmar 1931 Allbrook 1957 Jonck and Niekerk 1961) In lateroflexion the joint space becomes wedge-shaped with the narrow end pointing craniad on the concave and caudad on the convex side of the resulting scoliosis (Dittmar 1930) A limit to the lateroflexion is set by the tip of the inferior articular process on the convex side hitting the superior articular process The range of movement is then only 5° to 10° at each level except L_5—S1 where little or no lateroflexion is possible (Leger 1955) Rotation of the lumbar spine seems to be a combination of flexion and lateroflexion whose limits are set by the synovial joints (Steindler 1955)

Owing to the lordosis of the lumbar spine gravity will tend to displace ventrad the vertebrae below the vertex of the lordosis (de Cuveland and Feser 1958) The L_3 vertebra constitutes as a rule this vertex (Duhs 1950 Sullivan and Miles 1959) It has been postulated therefore that the joints on the $L_{4-5}$and L_5—S_1 levels at least in part prevent such displacement (Davis 1961) Furthermore the frontal inclination of the facets and the dorsally wedge shaped disc of the L_5—S_1 segment is thought to constitute an anatomical basis for exposing the L_5—S_1 synovial joints to greater stress than the other synovial joints of the lumbar spine (Junghanns 1933) According to some investigators who have applied a load to spinal columns *post mortem* and measured the resulting expansion of annulus

fibrosus or increase in intradiscal pressure (Brown Hansen and Yorra 1957, Nachemson 1960) the synovial joints take up some of the load borne by the lumbar spine But other studies involving intradiscal pressure measurements in postmortal spines carrying a shearing load and intravital spines supporting a vertical load suggest that the load borne by the synovial joints must be a minute fraction of the whole (Nachemson 1963)

Osteoarthritis

A detailed survey of the whole literature on osteoarthritis — or as it also is called in many papers arthrosis deformans, hereinafter termed osteoarthritis — would obviously be beyond the scope of this work In the present investigation the morphological observations made in the synovial joints of the lumbar spine were evaluated against the background of our present knowledge about the morphological picture in osteoarthritis of the extremital joints Hence the gross and microscopic anatomy of these joints in osteoarthritis will be described on the basis of previous workers morphological observations in autopsy specimens Furthermore such papers will be surveyed which describe investigations illuminating the pathogenesis and aetiology of osteoarthritis

Morphology of the Osteoarthritic Joint

Introduction

The morphological alterations characterizing osteoarthritis have long been well established (Ecker 1843 Weichselbaum 1877 Nichols and Richardson 1909 Pommer, 1913) Chondral and subchondral osteoarthritic changes always appear in the same order The chondral changes set in first and are dominated by degenerative phenomena in due course leading to necrosis and substance losses in the articular cartilage The subchondral changes on the other hand are far less dominated by such degenerative manifestations as atrophy and necrosis of the cancellous bone trabeculae Instead they mainly take the form of proliferation of vessels and connective tissue followed by osteoneogenesis leading to subchondral remodelling and osteophyte formation (Pommer 1913) The articular cartilage begins to exhibit gross osteoarthritic changes including necrosis and substance losses around age 30 (Heine 1926 Parker Keefer Mayers and Irwin 1934 De Palma 1950, 1957 Olsson 1953) At autopsy the frequency of such changes in say the hip or knee joint is 20 to 30 per cent in the 40—50 years age group and of the order of 60 per cent around and over age 60 (Heine 1926) Roentgenographic evidence of osteoarthritis is encountered in about 20 per cent of the hip joints and 40 per cent of the knee joints in large series of normal subjects around the age of 60 years (Kellgren and Lawrence 1958)

Osteoarthritis shows a marked tendency, in both controls and clinical series concurrently to affect multiple extremital joints (van der Meer 1945, Kellgren and Lawrence 1958) Women are apparently more susceptible to this than men and their knee joints, unlike their hip joints, are also affected more often (Heine, 1926, Holmdahl and Ingelmark, 1946 van der Meer, 1945, Kellgren and Lawrence, 1958) In both sexes the large joints of the lower extremities show a higher frequency of osteoarthritis than those of the upper extremities (Heine, 1926)

Gross Anatomy

The cartilage in the osteoarthritic joint has a greyish white to greyish yellow hue Its surface seems rough Here and there it is thinner than elsewhere If the cartilage is extremely thin it acquires a greyish red tone owing to reflexion from the marrow spaces in the subchondral bone Eventually a stage is reached where extensive portions of the cartilage are missing entirely exposing the underlying bone

Exposed areas of the subchondral bone plate have a more or less eburnated appearance In sections through the head or socket of a joint the subchondral bone plate and the cancellous trabeculae are thickened and the marrow spaces remarkably small in such exposed regions but the bone plate and the trabeculae often are abnormally thin in the unexposed regions (Weichselbaum 1877 Nichols and Richardson, 1909, Lang 1924) Besides these changes cystic formations occur in the subchondral bone in joints with advanced osteoarthritis (Lang 1924 Heine 1926 Harrison Schajowicz and Trueta 1953 Grueter and Rutt, 1962)

The synovial membrane in the early stages of osteoarthritis seems more or less marked oedematous and its villi are increased in both numbers and size In advanced stages the entire joint capsule is tightened and conspicuously thickened and osteophytes are present adjacent to its attachments (Weichselbaum 1877 Nichols and Richardson 1909 Pommer, 1913 Lloyd—Roberts 1953)

Microscopic Anatomy

Microscopic changes in osteoarthritis initially appear in the intercellular substance of the joint cartilage in the form of diffuse fibrillation owing to so called demasking of the fibrils normally embedded in the ground substance Concomitantly the chondrocytes vanish from some regions while they remain relatively unaffected or even become more numerous in other regions (Pommer 1913 Lang 1924 Heine 1926) Cracks appear at an early stage in the superficial cartilage layer These cracks develop into deep fissures which in the intermediate zone in vertical sections through the cartilage extend perpendicularly to the cartilage sur

face The cartilage thus splits up and takes on a more or less fringed appearance (Ecker, 1843 Weichselbaum, 1877 Nichols and Richardson, 1909) The calcified zone shows irregular thickening and is here and there pierced by vessels from the subchondral marrow spaces Absorption cavities are often seen in the cartilage around the points of entry of these vessels (Pommer, 1913 Lang 1924) The cartilage s cellular pattern now is markedly abnormal in that the ovoid chondrons disposed parallel to the surface are irregularly distributed have a more rounded shape and/or exhibit necrosis Although the cell density in the intermediate and radial zones diminishes any chondrons remaining show cell proliferation leading to the formation of giant chondrons The chondrocytes in these are en larged and ultimately destroyed by progressive dilatation These cellular changes cause regional necrosis of the cartilage in advanced cases (Weichsel baum 1877 Nichols and Richardson 1909 Pommer 1913 Lang 1924 Heine 1926)

As the destruction of the articular cartilage progresses changes appear in the subchondral bone Initially one sees connective tissue proliferation in the marrow spaces and thickening of the subchondral bone plate as well as of the cancellous bone trabeculae The thickening of the bone plate and trabeculae is confined to those areas of the subchondral bone which have been exposed by losses of articular cartilage substance Between such regions of so called subchondral sclerosis the marrow spaces are often widened contain a higher proporption of connective tissue and are separated only by thin bone slivers (Weichselbaum 1877 Nichols and Richardson 1909 Pommer 1913 Lang 1924 Heine 1926) At the stage when the articular cartilage exhibits necrosis and substance losses abnor mal perforations often appear in the subchondral bone plate Through these perforations more or less highly vascularized connective tissue from the marrow spaces enters the basal cartilage region or they may be plugged by cartilage When proliferating connective tissue from the subchondral marrow spaces has filled an articular cartilage defect it may be trans formed into fibrocartilage in which both calcification and formation of new bone take place (Pommer 1913 Lang 1924 Heine 1926 Harrison Schajowicz and Trueta 1953 Grueter and Rutt 1962)

Cartilage inclusions are encountered more or less deeply within the subchondral bone either adjacent to defects in the bone plate — when they have more or less distinct contacts with the articular cartilage — or embedded in connective or osseous tissue within the marrow spaces It has been postulated that these cartilage inclusions may be absorbed leaving behind them cystic formations (Pommer 1913 Heine 1926) Subchondral cysts are almost invariably present in advanced stages of osteoarthritis They may be anything from one or two up to about ten millimetres in

diameter These cysts may communicate with the joint cavity Their contents is very variable Sometimes it consists of connective tissue foci enclosed in a bone capsule In other cases they have a mucoid content encapsulated in osseous or connective tissue The connective tissue in and around such cysts may be loose and rich in vessels (Harrison Schajowicz and Trueta, 1953 Rutt, 1958 Grueter and Rutt, 1962)

The subchondral changes are accompanied by bone formation along the margins of the joint This gives rise to the marginal spurs or osteophytes typical of osteoarthritis They have marrow spaces and blood vessels communicating with those within the subchondral bone Only a few vessels give the impression of arising from the synovial membrane and/or the periosteum (Pommer, 1913, 1927 Lang 1924, Heine 1926 Harrison Schajowicz and Trueta 1953 Lloyd Roberts 1955)

The joint capsule exhibits changes confined to the synovial membrane so long as the osteoarthritic changes are exclusively chondral These early changes in the synovial membrane comprise proliferation of cells in the superficial layer, minor perivascular infiltrations of round cells and a somewhat increased number of vessels Later when chondral as well as subchondral osteoarthritic changes are present the synovial membrane is usually transformed into more or less markedly fibrous and poorly vascularized connective tissue making it indistinguishable from the fibrous layer of the capsule The whole capsule concomitantly exhibits thickening (Lloyd Roberts 1953 Schmitz 1955 Rutt 1958 Grueter and Rutt 1962)

Pathogenesis and Aetiology

Most of those who have studied the problem of osteoarthritis unreservedly agree that changes in the articular cartilage are primary (Weichselbaum 1877 Nichols and Richardson 1909 Pommer 1913, 1927, Lang 1924 Heine 1926, Bennett Waine and Bauer 1942 Harrison Schajowicz and Trueta 1953 de Palma 1957 Grueter and Rutt 1962) These changes are predominantly manifestations of degenerative processes such as fibrillation necrosis and losses of substance Certain phenomena however like the accumulation of chondrocytes seen around cartilage defects induced experimentally (Bennett and Bauer 1935) or by the osteoarthritic process itself (Pommer 1913) should probably be interpreted as restorative processes (Carlsson 1957)

Aetiologically osteoarthritic changes are ascribed to the actions exerted upon the cartilage by articular function and nutrition (Ecker, 1843 Weichselbaum 1877 Pommer 1913 Bennett Waine and Bauer, 1942 Harrison Schajowicz and Trueta 1953 Rutt and Hackenbroch 1957)

Normal articular function abrades the surface of the joint cartilage (Hammar 1894 Hulten and Gellerstedt 1940 Ekholm and Norback

1951) Renewal apparently takes place from the articular cartilage's intermediate zone whose cell density has been shown to rise following increased activity (Saaf 1950) New cells are formed by amitotic division (Elliot, 1936) and losses of intercellular substance are replaced The chondrocytes are involved in the latter process to the extent that the interfibrillar ground substance is synthetized intracellularly and their system of α cytomembranes seem to produce a prestage of the collagen fibrils (Zelander 1959) The ability to form new cells and to regenerate tissue diminishes with age (Elliot 1936 Calandruccio and Gilmer, 1962 Hall 1963)

The articular cartilage is elastic and this property is intimately associated with the state of the intercellular substance (Benninghoff 1925 Hirsch 1944 Pauwels 1959) In the ageing cartilage the composition of the intercellular substance undergoes changes among other things its chondroitin sulphate content falls leading to reduced elasticity (Hirsch, 1944 Eichelberger and Roma 1954) The ability of the articular cartilage to withstand the strains of mechanical movements and of bearing loads accordingly diminishes with age

The subchondral vascular bed and the synovial fluid constitute the sources of nourishment for the articular cartilage (Ekholm 1951 1955 Brodin 1955) Articular function seems to promote the nutrition the passage of nutrients into the cartilage from the subchondral vascular bed rises when joint function commences (Ingelmark and Saaf, 1948 Ingelmark 1950) This passage can longer be maintained on a high level if the joint is exposed to intermittent exercise than a static (Ingelmark and Ekholm 1948 Ekholm and Ingelmark 1952) Against this background it has been adduced that, by interfering with the nutrition of the cartilage unsuitable articular function is capable of producing alterations of the cell pattern and in the intercellular substance which in turn lead to degenerative and regenerative changes in the articular cartilage (Harrison Schajowicz and Trueta 1953 Salter and Field 1960 Trias 1961)

Undernutrition of the articular cartilage with attendant osteoarthritic changes has also been ascribed to impaired circulation either in the subchondral vessels (Muller 1924 Phemeister 1940) or in the vessels of the synovial membrane (Strangeways 1920 Lacapere and Drieux 1952) Yet few authors have claimed that vascular disturbances in and around the joint constitute the most common cause of osteoarthritic chondral changes (Wollenberg 1909 Goldhaft *et al* 1930)

Osteoarthritic changes do not appear subchondrally until the chondral ones have progressed to a fairly advanced stage (Weichselbaum 1877 Nichols and Richardson 1909 Axhausen and Pels 1911 Pommer 1913

Heine, 1926, Harrison Schajowicz and Trueta 1953) Changes in the subchondral bone are consequently interpreted as more or less dependent on, and as a response to, those in the articular cartilage (Pommer, 1913, 1927, *Harrison Schajowicz and Trueta 1953) This hypothesis receives* strong support from the fact that in certain circumstances cartilage defects induced in experimental animals give rise to a subchondral morphological picture typical of osteoarthritis Superficial defects are healed by tissue regeneration from the surrounding intact cartilage without producing any alterations in the morphological appearance of the subchondral bone But if the artificial defects extend into the calcified zone of the articular cartilage a more or less profusely vascularized connective tissue appears subchondrally (Carlsson 1957 Evans Eggers Butler and Blumel 1960)

Connective tissue proliferation in the subchondral bone and hypertrophy of its cancellous trabeculae in osteoarthritis are regarded as its response to *increased mechanical stimulation* And the subchondral appearance of osseous atrophy necrosis and cystic formations are interpreted as degenerative phenomena in osteoarthritis following reduced or completely absent mechanical stimulation (Pommer 1913 1927 Muller, 1924 Bennett and Bauer 1935 Fischer 1922, Bennett Waine and Bauer, 1942) As mentioned the subchondral bone often displays proliferative and degenerative changes at the same time It remains to be demonstrated, however that this is because the presence of chondral osteoarthritic changes redistributes the load on the articular surface, increasing it in some parts and reducing it in others Nevertheless, it has been shown in animal experiments that the general loading conditions in the joint are of significance for the onset and course of osteoarthritic changes that progress to involvement of the subchondral bone Joint immobilization alone merely produces degenerative chondral changes while immobilization combined with compression yields a morphological picture similar to osteoarthritis both in the articular *cartilage and in the subchondral bone (Wehner 1923 Salter and Field* 1960 Trias 1961 Calandruccio and Gilmer, 1962) Some workers are of the opinion that ingrowth of subchondral vessels into the degenerated articular cartilage is merely an attempt to revitalize the latter having nothing to do with increased loading of the subchondral bone (Harrison Schajowicz and Trueta 1953)

The formation of new bone along the margins of the joint is preceded by invasion of connective tissue from the subchondral marrow spaces (Pommer 1913 1927 Lang 1924 Harrison Schajowicz and Trueta, 1953) During the initial stages of osteophyte development vascularization apparently takes place also from neighbouring synovial tissue and/or periosteum During the continued development and growth of osteophytes, however new bone is formed mainly in fibrocartilage produced by the

connective tissue growing in from the subchondral marrow spaces (Harrison Schajowicz and Trueta 1953)

The subchondral cysts are as mentioned regarded as degenerative phenomena confined to those subchondral bone regions underlying articular cartilage with advanced changes By overloading the bone this would result in either atrophy or traumatization of the cancellous bone trabeculae (Harrison Schajowicz and Trueta 1953 Rhaney and Lamb 1955 Rutt 1958, Grueter and Rutt 1962) Absorption of attendant necrosis would lead to cyst formation It has alternatively been adduced that synovial fluid pressed into the subchondral bone by way of articular cartilage defects by osteolysis causes the subchondral cysts (Landells 1953) It does not seem established however whether synovial fluid possesses osteolytic activity Regenerative processes commence within the cysts especially within those immediately beneath the subchondral bone plate secondary to ingrowth of vascularized connective tissue (Grueter and Rutt 1962)

Apart from osteophytes adjacent to its attachments the joint capsule exhibits progressive fibrosis believed to commence with the proliferation of synovial membrane cells around accumulations of small cartilage fragments Accumulation of such cartilage fragments is held to be a direct consequence of the increased abrasion of the articular surfaces in an osteo arthritic joint (Lloyd Roberts 1953)

Osteoarthritis of the Lumbar Synovial Joints

Gross Anatomy

The gross appearance of lumbar synovial joints with osteoarthritis of various degrees is similar in principle to that of osteoarthritis of the extremital joints The initial manifestations are thus that the articular cartilage exhibits a yellow discolouration and has a rough surface More or less extensive cartilage defects and osteophytes appear in due course and occasionally one encounters joints with fibrous and/or true ankylosis (Guntz 1934)

Osteoarthritic changes in the subchondral bone plate and capsular attachments have moreover been studied in skeletons (Guntz 1934 Shore 1935 Ingelmark 1956 1959) In the early stages the subchondral bone plate displays porosity which later turns into larger perforations in the bone plate and it also shows uneven thickening In advanced stages the bone plate has fewer but larger holes is markedly sclerotic and has eburnated patches Marginal osteophytes appear concomitantly with these changes particularly on the dorsal rim of the joints (Ingelmark, 1956, 1959)

A wedge-shaped, or narrowed or widened joint space more or less pronounced subchondral sclerosis and osteophytes in the roentgenogram have been interpreted as evidence of osteoarthritis of the lumbar synovial joints (Lange, 1933, 1936 Oppenheimer, 1943 Keller 1953) For roentgenographic studies oblique projections have usually been adopted with an angle of incidence of the central ray on the sagittal plane of around 45° (Dittmar, 1931) But the configuration of the lumbar synovial joints is such that their joint space readily can be destorted in roentgenograms (Reichmann 1963)

Microscopic Anatomy

The microscopic appearance of osteoarthritis in the lumbar synovial joints does not seem to have been followed systematically Brief accounts have nevertheless been given in conjunction with reports on grossly visible osteoarthritis (Guntz, 1934 Ingelmark, 1956, 1959) or in the course of discussions relating to the mechanical action of intervertebral disc degeneration on the function of the lumbar synovial joints (Keller, 1953, Harris and Macnab 1954)

Fibrillation and cell proliferation have thus been noted in the articular cartilage in early stages of osteoarthritis when it exhibits gross yellow discolouration and roughening of the surface (Guntz 1934) As described with respect to extremital joints (p 12) these chondral changes progress towards fringing of the cartilage with consequent loss of substance and exposure of the subchondral bone plate (Guntz 1934 Harris and Macnab 1954) At this stage the cartilage grossly displays an uneven and course surface here and there discoloured greyish red Subchondral sclerosis and formation of new bone are distinctly visible in histological sections (Guntz 1934) In conformity with the observation on skeletons that one of a joint s articular surfaces may exhibit only minor changes while the other shows sclerosis perforations in the subchondral bone plate and osteophytes, microscopic examination too sometimes reveals considerable differences between the same joint s articular surfaces The surface of one cartilage may have a normal cell pattern while its mate may present marked cell proliferation Indeed in extreme cases a tolerably well preserved cartilage can touch exposed portions of the opposite subchondral bone plate of the other (Guntz 1934)

Frequency and Distribution

The frequency and distribution of osteoarthritic changes in the spinal synovial joints has been studied both on skeletons (Shore 1935 Ingelmark 1956 1959) and in autopsy specimens (Guntz 1934 Putti and Logróscino 1937 Horwitz and Smith 1940) Shore examined a series of 126 spinal columns from skeletons of unspecified age and sex distribution Osteo

arthritis was considered present if osteophytes were found along the margins of the joint's articular surfaces Such osteophytes were often encountered around the middle of the anatomical regions of the spine The lumbar spine had the highest frequencies, with an absolute peak incidence for the spine as a whole at the L_{2-3} level where about 65 per cent of the joints had osteoarthritic changes Caudally of the L_{2-3} level osteoarthritis gradually became less frequent its incidence being approximately 35 per cent at the L_5—S_1 level In the cervical and thoracic regions of the spine the peak osteoarthritis frequencies were noted at the C_{3-4} and Th_{4-5} levels both being of the order of 25 per cent

Ingelmark studied spinal columns from a series of 138 male and 73 female mediæval skeletons The criteria of osteoarthritis were porosity of the articular surface sclerosis of the subchondral bone plate osteophytes in the joint capsule attachment region on the articular process and ankylosis of the joint In the series as a whole these types of osteoarthritic changes showed a considerably higher frequency within the cervical and thoracic regions than within the lumbar spine While in the two former regions 27 and 22 per cent respectively of the total number of joints were affected the same was the case of only 9 per cent of the joints in the lumbar spine Within complete spines there was a frequency maximum of approximately 35 per cent at the C_{3-4} level and another at the Th_{4-5} level of about 38 per cent No definite frequency differences between levels could be demonstrated in the lumbar region but the L_{4-5} level showed the highest relative frequency namely 10 per cent No differences were noted between sexes

The average degree of the osteoarthritic changes as judged by a point scoring system was substantially similar in the cervical thoracic and lumbar regions Among the lumbar synovial joints those at the L_{4-5} level exhibited the highest average score for osteoarthritic changes Approximately 5 per cent of the total number of lumbar synovial joints had one articular surface more affected than the other Only one of the articular surfaces was affected in 2 per cent of the joints The superior and the inferior articular surface were equally often more affected

Guntz (1934) studied the thoracic and lumbar synovial joints in 56 autopsy cases of unspecified age and sex All the joints were opened and grossly examined for the presence of osteoarthritic changes which were graded according to degree The gross appearance of some of the joints was as mentioned elsewhere (p 18) checked by microscopic examination

Below age 30 all joints were grossly normal Although Guntz did discuss how the frequency of osteoarthritic changes was related to rising age he did not state whether his figures were based on complete spines or the total number of joints examined Accordingly such figures as 30 per cent

at age 45 and 50 per cent at age 65 are ambiguous Frequencies of affected joints in the series as a whole are on the other hand, specified for each level and each side The frequency of joints showing osteoarthritic changes rose rapidly from about 10 per cent in the upper part of the thoracic spine to some 60 per cent at the levels Th_{3-4} Th_{4-5} and Th_{5-6}, whereupon it once more fell to around 30 per cent in the lower part of the thoracic spine Then it gradually rose to some 55 per cent at the L_{4-5} and L_5—S_1 levels A difference between the right and left sides of at most 10 per cent was found only at the L_1—L_2 and L_5—S_1 levels, the right side being preponderant Ankylotic joints were encountered exclusively in the thoracic region around the Th_{4-5} level

Putti and Logroscino (1937) studied the occurrence of gross osteoarthritic changes in 42 male and 33 female lumbar spines from autopsy cases The 4 spines in the 18—30 years age group all had grossly normal joints All lumbar spines over 30 years of age exhibited gross osteoarthritic changes which became progressively more severe with rising age More than 50 per cent of the 33 lumbar spines from subjects over 60 years of age exhibited advanced or grave osteoarthritis in one or more joints The distribution of osteoarthritic alterations within lumbar spine levels showed that in the series as a whole the proportion of affected joints was merely some 60 per cent at the L_{1-2} level *versus* over 80 per cent elsewhere The highest frequency in the lumbar spine — approximately 90 per cent — was encountered at the L_{4-5} level

In an investigation designed to seek optimal oblique projections for roentgenographic examination of the lumbar synovial joints Horwitz and Smith (1940) used an autopsy series from 76 males and 4 females and recorded the frequency of gross osteoarthritic changes Gross chondral changes and osteophytes were observed in one or more joints of 31 per cent of the spines No mention is made of the distribution by age or level of these osteoarthitic changes

Examining roentgenographically 368 subjects, a random sample of every 10th inhabitant of Leigh town Lancashire, Kellgren and Lawrence (1958) found that the frequency of subjects with osteoarthritic changes in the cervical and lumbar synovial joints was 25 and 30 per cent, respectively, there being no frequency difference between the sexes The absence of information about the roentgenographic method however, makes it difficult to assess the value of this investigation

Aetiology

Apart from being a phenomenon associated with ageing osteoarthritis has been assumed secondary to congenital deformities structural scoliosis disc degeneration and trauma

In intervertebral disc degeneration increased range of mobility of all moving parts in the segment has been demonstrated (Knutsson, 1944, Friberg and Hirsch 1949 Jirout 1959) as well as changes in the mechanical response within the disc itself (Ingelmark and Ekholm, 1952 Hirsch and Nachemson 1954, Hirsch 1955 Brown Hansen and Yourra 1957 Nachemson 1960)

Several workers have expressed the view that osteoarthritis more or less often may be secondary to disc degeneration in the lumbar spine (Schmorl 1931, 1932 Junghanns 1931, 1933 Hildebrandt 1933 Severin 1943 Keller 1953) the presumed causative factor being functional disturbances of the type mentioned above Notably however nobody has given any information on the degree and frequency of the osteoarthritis accompanying disc degenration to support this view Conversely Guntz (1934) adduced that normal and degenerated intervertebral discs are accompanied by osteoarthritic changes equally often He added however, that autopsy specimens with disc degeneration of high degree and consequently segmental instability invariably exhibited osteoarthritic changes No absolute numbers are specified The same criticism may be raised against Harris s and Macnab s (1954) study of 123 lumbar spines from autopsy cases of all ages Their most remarkable statement is that osteochondral fractures fairly often accompanied disc degeneration Ingelmark (1956 1959) demonstrated that a weak though definitely positive correlation exists between lesions of the vertebral bodies and osteoarthritic changes in the spinal synovial joints Grave changes in either the vertebral body joints or the synovial joints are usually combined with changes of similar degree in the other type of joint in the same segment

At roentgenographic examinations Lange (1933 1936) found that in the lumbar spine osteoarthritis of the synovial joints was closely associated with scoliosis He supported this statement not with statistical data but with case reports The same applies to others (Guntz 1934 Putti and Logròscino 1937 Tager 1964) who have postulated that osteoarthritis often is secondary to scoliosis

Asymmetries in shape size and inclination of the joint facets have also been regarded as a major factor in the causation of osteoarthritis especially in the lumbosacral region of the spine (Putti 1927 Putti and Logroscino 1937) Studying a series of 80 lumbar spines from autopsy cases Horwitz and Smith (1940) found that 8 of the 24 with osteoarthritic changes also exhibited asymmetry of the lumbosacral joint facets contralateral facets being differently inclined towards the sagittal plane Brailsford (1929) roentgenographically demonstrated asymmetrically inclined joint facets in about 30 per cent of over 3000 subjects although only one of them had roentgenographically manifest osteoarthritis Among an unspecified

number of patients with various back disorders Smith (1934) found 55 in whom dorsal displacement of the 5th lumbar vertebra was associated with abnormal inclination of the sacral joint facets But only a few of them had concommitant osteoarthritis Southworth and Bersack (1950) reported Putti s (1927) anomaly of articular tropism at the L_{4-5} level in 26 5 per cent and at the L_5—S_1 level in 17 4 per cent of 550 subjects without back symptoms who were examined roentgenographically This anomaly in the lumbar spine was present in 54 of 233 subjects under 40 years of age, although none exhibited either scoliosis or osteoarthritis of the lumbar synovial joints Distinct asymmetry — a difference of about 15° between the inclinations of the right and left joint facets in relation to the sagittal plane through the vertebra — has a frequency of approximately 10 per cent in large series of skeletons (Badgley 1941, Jonck, 1961) Similar frequencies have been encountered in comprehensive series of roentgenograms of children s backs (Kuhns, 1935) On the basis of osteometric observations on the thoracic and lumbar vertebrae from 20 entirely normal skeletons between 19 and 86 years of age Farkas (1941) drew the conclusion that such asymmetries are dependent upon and a normal feature of physiological scoliosis This conclusion may receive support from the fact that asymmetry of the occipital condyles has been shown to become evident not until the first year of life and to increase in frequency with age (Ingelmark 1943) Asymmetry of the lumbar synovial joints may also develop on the basis of congenital hypoplasia of the joint facets (Brocher, 1950)

In addition to mechanical abnormalities of the lumbar segments it has been adduced that rheumatoid arthritis in the spinal synovial joints may precede and induce the osteoarthritic changes (Oppenheimer, 1943) Reporting the results of a roentgenographic study of 1200 subjects with and without back complaints, Gantenberg (1930) stated that intervertebral disc degeneration in many cases was accompanied by rheumatoid arthritis in the lumbar synovial joints

CHAPTER 2

Material

This investigation is based on observations made in a series of 104 lumbar spines from 86 subjects over and 18 under 20 years of age All the former and 8 of the latter had been collected by Friberg and Hirsch in the years 1946—1948 at autopsies in Stockholm hospitals the remaining 10 being taken by this writer from corpses autopsied in Gothenburg hospitals Every synovial joint and intervertebral disc in the 86 lumbar spines from subjects over 20 years of age was examined systematically for morphological abnormalities The information thus obtained was used for a statistical analysis of changes in the vertebral body joints as well as in the synovial joints The age and sex distribution of the 86 adult lumbar spines will be found in Table 1

The 18 lumbar spines from young persons up to 20 years of age were studied with respect to the microscopic anatomy of the synovial joints particular attention being paid to any pathological changes therein The age distribution of the young lumbar spines is presented in Table 1

TABLE 1

Age and sex distribution of lumbar spines over 20 years of age and age distribution of lumbar spines up to 20 years of age

Age groups	Women	Men	No
20—25 years	4	7	11
26—35 years	8	8	16
36—45 years	9	7	16
46—55 years	7	12	19
56—65 years	3	11	14
> 65 years	3	7	10
No	34	52	86

Age years	0—1	1—5	6—10	11—15	16—20	No
No	4	6	2	4	2	18

The series of lumbar spines was unselected in the sense that it did not come exclusively from subjects with or without back disorders during life No lumbar spine was taken, however, from autopsy cases in which the cause of death was a tumour or tuberculosis, in order to exclude spines with tumour metastases or tuberculous spondylitis The autopsy report was scrutinized, moreover for every spine subjected to systematic examination of the synovial joints and intervertebral discs But the pathological conditions described by the pathologist were in no case such as might have had any direct effects upon the state of the discs and/or joints Those spines used for microscopic examination of the synovial joints were dissected and prepared for further histotechnical treatment on the same day as, or at the latest the day after, the autopsy In the latter event the spines were stored in a refrigerator during the interval between autopsy and dissection

Spondylolysis or spondylolisthesis was seen in 4 cases altogether None of the spines exhibited evidence of fixed scoliosis in the lumbar region

None of the spines exhibited evidence of fractures or hypoplasia of the articular processes

* * *

The association between morphological changes and roentgenologically visible abnormalities in the vertebral body joints in the present series of lumbar spines has been studied by Friberg and Hirsch (1949) It appeared that 17 of the 100 spines examined exhibited roentgenological evidence of intervertebral disc degeneration in the form of reduced disc thickness, osteophytes on the edges of the vertebral bodies and sclerosis of the subchondral bone of the vertebral bodies The corresponding discs all displayed very advanced morphological changes

Flexion and extension of the lumbar spine preparations was accompanied by, respectively, ventrad and dorsad diplacement of more than 5 mm — in other words so called instability as defined by Knutsson (1944) — of the L_4 vertebra in relation to the L_5 vertebra in 12 of the spines In these spines the disc in the L_{4-5} segment exhibited total or subtotal ruptures of annulus fibrosus Prolapse of nucleus pulposus tissue was en countered in the L_{4-5} and/or L_5—S_1 segments of altogether 11 spines In these discs with nucleus prolapse the morphological changes were in other respects grossly indistinguishable from those presented by other discs with degeneration only

Both the gross and the microscopic intervertebral disc changes in this series of lumbar spines have been described by Hirsch and Schajowicz (1952) Approximately 40 per cent of the discs in the L_{4-5} and L_5—S_1 segments of spines older than 45 years displayed radiating ruptures of

the annulus fibrosus Such ruptures were less common in the other discs in the lumbar spine Below 20 years of age the discs exhibited merely microscopic changes in the form of small ruptures in the innermost lamellae of the annulus fibrosus Microscopic examination of grossly visible ruptures almost invariably disclosed the presence of more or *less richly vascularized connective tissue growing into and around the* ruptures from the connective tissue located marginally in the disc adjacent to the posterior longitudinal ligament

CHAPTER 3

Methods

Preparation Techniques

All specimens collected 1946—48 and later were treated in the following way All muscle having been dissected away, the lumbar spine preparation was roentgenographed in the frontal projection with the vertebrae resting normally on top of each other and in the lateral projection in the same position as well as in positions of maximal flexion and extension as achieved by manual bending of the lumbar spine when the sacrum was fixed in a screw clamp These roentgenograms were used for studying disc thickness vertebral bodies and synovial joints In addition instability, as defined by Knutsson (1944), and subluxation as defined by Hadley (1936, 1951) and others, *were registrered*

The body and arch of each vertebra were now separated by sawing through the pedicles, whereupon the synovial joints were subjected to histotechnical preparation Each intervertebral disc was divided into two parts of equal thichness, the gross appearance of the cut surfaces being noted, which were photographed and prepared for microscopic examination

After fixation in 10 per cent formalin solution and decalcification with hydrochloric acid according to Ebner, each synovial joint was devided into three parts of roughly the same size by cuts perpendicular to the cranio caudal axis of the joint in situ Each such joint portion was embedded in *paraffin and 4 or 5 sections approximately 5 μ thick were cut from it on* a conventional microtome In this fashion a sample was obtained at about every 4th millimeter of the joint

For the purposes of the investigation originally performed on these lumbar spines only two sections had in most cases been taken from each joint and stained with Ehrlich s Haematoxylin eosin Consequently further sectioning was required for the present investigation occasionally following renewed decalcification in a mixture of equal volumes of concentrated formic acid and 7 per cent sodium formiate solution These new sections were stained by either Delafield s or Bock-Hansen s haematoxylin eosin procedures

Principles for Gauging Changes of Synovial Joints and of Vertebral Body Joints

Synovial Joints

The microscopic appearance of the synovial intervertebral joints was as mentioned studied in sections taken about 4 millimetres apart along the long axis of the joint This should be adequate in regard to changes in the joint cartilage which show a marked tendency to span the entire craniocaudal extent of the joint facet (Fig 3) Minimal changes in the subchondral bone and capsular attachments on the other hand might occasionally be missed *Any joint with one or more structures showing unmistakeable evidence* of damage during histotechnical preparation was discarded unless its preserved portions presented consistent and pronounced changes

The morphological appearances of the concave (on superior articular process) and convex (on inferior articular process) surfaces of each joint were examined in the microscope and rated separately 0 representing normal conditions 1 mild *to* moderate changes and 2 marked *to* advanced changes The results of the examination were thus converted to a form suitable for statistical analysis The following structural details of the synovial joints were taken into consideration

A Uncalcified articular cartilage

(a) Cell pattern

GRADE 0 Cells clustered in distinct strata

GRADE 1 Irregular cell distribution cells disposed in so called nests more or less marked cell enlargement

GRADE 2 Cell paucity and/or necrosis

(b) Appearance of intercellular substance

GRADE 0 Unstructured intercellular substance smooth or only slightly rough cartilage surface

GRADE 1 Fringing of cartilage surface and fissures of varying depth in cartilage with denudation and fibrillation of inter cellular substance undiminished cartilage thickness

GRADE 2 Tissue losses and/or necrosis in articular cartilage

B Calcified articular cartilage

GRADE 0 Calcification confined to basal portions of cartilage *encompassing approximately one* fifth of its total thick ness

GRADE 1 Somewhat thickned and conspicuously irregular calcified zone

GRADE 2 Markedly thickened calcified cartilage zone

C Subchondral bone

GRADE 0 The subchondral bone forms a distinct lamella towards, the articular cartilage, contacts established through this lamella between calcified cartilage zone and bone marrow vessels by vascular budding

GRADE 1 Here and there thickening of the subchondral bone lamella which exhibits fissures wherein cartilage fragments are lodged, occasional marrow spaces contain connective tissue regions

GRADE 2 Trabecular thickening and/or large marrow spaces, extending as far as the basal cartilage portions Marrow spaces wholly or partly filled with more or less richly vascularized connective tissue which via defects in the subchondral bone lamella in places infiltrates the calcified cartilage layer

D Capsular attachments

GRADE 0 Smooth transition at joint periphery of hyaline cartilage via fibrous cartilage to fibrous capsular layer, Distinct capsular attachments

GRADE 1 Minor osseous deposits marginally and synovial tissue fibrosis

GRADE 2 Pronounced marginal osteophytes and, adjacent to capsular attachments metaplasia of fibrous capsular layer into cartilage and/or connective tissue

Coexistence of chondral changes of grade 2 for the cell pattern and the intercellular substance and of subchondral changes of grade 1 or 2 in the same facet was taken as evidence of osteoarthritis (A a = 2 + A b = 2 + C = 1 or 2 + D = 1 or 2 See preceding section)

The above rating system was used for coding the morphological appearance of the joint facets, with the criterion that at least three sections from every facet had to attain identical scores When the entire series had been examined in this manner without knowledge of sex or age, every section was re-examined in the microscope and a statement of the morphological picture of each joint facet was recorded in synoptic form The statement was always based on those sections exhibiting the most consistent and pronounced degrees of any morphological changes The results of these two examinations were then collated It turned out that the numerical code and the synoptic statement were not quite in agreement with respect to a very few joint facets in occasional lumbar spines To eliminate the few instances of personal bias that had thus become manifest, the whole series was examined a third time and recoded in accordance

with the same rating system as before This time the results showed adequate agreement with the synoptic statements The statistical analysis was consequently based on the latter coding But had it been based on the former the results would not have deviated significantly, for within age groups the mean scores at the first and second numerical coding merely exhibited occasional minor differences Lastly those joints which as defined elsewhere (p 28) were deemed to represent the condition of osteoarthritis were scrutinized a fourth time and found to have a morphological picture well satisfying the criteria adopted for justifying the microscopic diagnosis of osteoarthritis

Against the background of the observations made in the course of the aforementioned examinations, a general assessment was made of the overall picture presented by all the joint facets in each lumbar spine This general assessment was used as the foundation for a description of the histological picture of the synovial joints under normal conditions as well as in various degrees of morphological changes

There is a danger that changes in the capsular attachments will be overrepresented unless some peculiarities of the normal anatomical relations of the synovial joints of the lumbar spine are known On the dorsal aspect of the superior articular process the capsular attachment extends immediately medial to the mamillary process on which insert the central fibres of the multifidus muscle as well as the outer fibrous layers of the joint capsule (Fig 4) Changes in those structures inserting on the mamillary process may occasionally give the impression of being osteophytes in the joints Such changes however should rather be interpreted as metaplasia of the transitional zone between bone and fibrous tissue as described by Kneese and Biermann (1958) and others—and are in no way related to any joint changes To some extends this holds true also for those regions wherein ligamentum flavum attaches to the articular processes with metaplasia to osseous tissue (Fig 5) The only true osteophytes in the synovial joints are those situated intracapsularly which have marrow spaces communicating with the subchondral ones (Fig 6)

Considering that the series of lumbar spines had been lying idle in sectioned and/or embedded form for comparatively many years prior to the present investigation it was felt that improved accuracy of assessment would be achieved by comparing the results with observations in a similar study of the synovial intervertebral joints in 10 fresh lumbar spines This comparison had the following results Just as the stored specimens exhibited cell proliferation and fibrillation of the intercellular substance in articular cartilages from subjects as young as 20—30 years the same was the case in articular cartilages in fresh lumbar spines from subjects of similar age When the latter specimens presented more pronoun

ced changes in the morphological picture of the synovial joints it had similar degenerative and restorative features as were encountered in the stored lumbar spines Nor was there any difference with respect to artefacts Thus the fresh autopsy specimens too included joints in which the articular cartilage, subchondral bone and joint capsule had been damaged during histotechnical preparation Among commoner artefacts the following may be mentioned fringing of the articular cartilage in some regions, separation of the cartilage s calcified regions from the subchondral bone fracture of the cancellous trabeculae with compression of the subchrondal marrow spaces detachment of the joint capsule or ligamentum flavum from its point of attachment on one of the articular processes

On the basis of these gradings the following cores were compiled to estimate the degree of osteoarthritic changes in the lumbar synovial joints

Articular structure	Code	Maximum points		
		Facet score	Joint score	Segment score
Cell pattern of articular cartilage	A a	2	4	8
Intercellular substance of articular cartilage	A b			
Calcified layer of articular cartilage	B			
Subchondral bone	C			
Capsular attachment	D			
Articular cartilage	A—B	6	12	24
Articular bone	C—D	4	8	16
Articular cartilage and bone	A—D	10	20	40

Vertebral Body Joints

The condition of the vertebral body joints was studied by grossly examining the intervertebral discs and by scrutinizing roentgenograms of each lumbar-spine preparation

The gross appearance of the intervertebral discs was gauged by inspection of photographs the grades given thereupon being collated with the corresponding grading by Friberg and Hirsch (In a prior study of intervertebral discs from some 30 fresh corpses of various ages the writer s experiences had made him thoroughly conversant with different stages of grossly visible disc changes) It turned out that the writer s assessment was in complete agreement with the original one except for a few instances when one or two of the discs in the photographs were interpreted as exhibiting a lower degree of changes than that originally assessed The classification of intervertebral disc changes proposed by Friberg Hirsch and Schajowicz was adopted (Cf Fig 7)

GRADE 0 Discs without changes visible to the unaided eye whose gelatinous shiny nucleus pulposus readily can be distinguished from the grossly unruptured annulus fibrosus

GRADE 1 Discs with gross changes in the nucleus pulposus which though somewhat more fibrous remains clearly distinguishable from the still intact annulus fibrosus

GRADE 2 Discs with gross changes in both nucleus pulposus and annulus fibrosus the former being rather fibrotic but still soft and the latter presenting occasional fissures The two are less clearly yet perceptibly demarcated

GRADE 3 Discs with marked gross changes in the form of fissures and/or cavities in both nucleus pulposus and annulus fibrosus

Any score of 2 or 3 was taken as evidence of disc degeneration

The appearance of any osteophytes occurring on the edges of the vertebral body in roentgenograms of the lumbar spine preparation in frontal and lateral projections was gauged in accordance with the following scale (cf Nathan 1962)

GRADE 0 The rim of the vertebral body is clearly demarcated from its cancellous portion in frontal and lateral projections

GRADE 1 The demarcation between the rim of the vertebral body and its cancellous portion is obscured by small up to ricegrain sized osteophytes

GRADE 2 The edges of the vertebral body exhibit large osteophytes in shape more or less closely resembling bird s beak

GRADE 3 Osteophytes bridge the gap between and render ankylotic adjacent vertebrae

The results were checked against the records of the previous investigation by Friberg and Hirsch concerning any osteophytes at dissection on the edges of the vertebral bodies By so doing it became possible to make allowance for projection distorsions

Statistics

Standard statistical methods were used The significance of differences between means were tested with the aid of Student s t Confidence limits were calculated on the assumption that the series agreed with the t distribution The significance of intercurrences of osteoarthritis disc degeneration and marginal vertebral osteophytes were analysed with the aid of X test When positiv intercurrences were found the productmoment correlation coefficient was employed

CHAPTER 4

Microscopic Anatomy of Lumbar Synovial Joints with and without Morphological Changes

Normal Joints

The appearance of the lumbar synovial joints during childhood and adolescence will not be discussed here The joints have stopped growing by about age 20 The articular process peripheral to the capsular attachment ceases to grow before the joint facet itself does so Hence the joint facets often seem to curve dorsally beyond the level of the articular processes elsewhere (Figs 8 9)

The surface of the articular cartilage is smooth in the adult In its central region the tangential zone is composed of three or four layers of oval cells with their long axis disposed parallel to the surface Next comes a hinted transitional zone with chondrons of three or four chondrocytes Most of the cartilage thickness is occupied by the radial zone where the chondrons are composed of six to eight comparatively large cells These chondrons have their long axis pedpendicular to the cartilage surface In the central parts of the cartilage it is thus justified to speak of a radial zone Not so in the marginal parts where only a superficial and a deeper zone can be distinguished from the cell pattern The former is continuous with the central tangential zone and the latter has its cells disposed as in the aforementioned transitional zone The transition between cartilage and capsule is gradual in the dorsal parts of the joint but rather abrupt towards ligamentum flavum and in the superior recess The intercellular substance of the cartilage is light microscopically structureless (Fig 10)

Next to the subchondral bone plate comes the calcified zone of the articular cartilage which uniformly occupies about one-sixth of the whole cartilage thickness (Fig 10 b) So-called vascular buds on the subchondral bone plate intrude into the calcified zone The marrow spaces in the subchondral bone are fairly small and uniformly spaced except that the cancellous trabeculae quite often are a little broader in the ventral portion of the articular process (Figs 4 10)

Joints with Morphological Changes

No evidence of specific or unspecific inflammation was observed in any of the lumbar spines The same applies to tumours and other diseases capable of affecting cartilage bone or connective tissue Nor were any fractured synovial joint facets encountered at either the microscopic or the roentgenographic examination

Changes of degenerative as well as proliferative types were observed often concurrently, in degrees progressing with age from trifling to profound In the absence of clearly demarcated stages the following description is based on an arbitrary classification into degrees that typically are not encountered before the ages of 30 45 and 60 years respectively

Degree I Some articular cartilages have a fairly irregular cell pattern either because there are very few cells in some regions or because of marked cell *proliferation centrally (Fig 11) Concomitantly the intercellular* substance is fibrous and the cartilage surface splits up by cracks the cells here and there in the tangential layer being lost or replaced by rounder cells in groups of three to five The cracks may develop into deep fissures in the cartilage For a short distance in the tangential zone these fissures usually run parallel to the surface and on reaching the transitional zone proceed towards the calcified zone in a direction perpendicular to the surface In such articular cartilages the thickness of the calcified zone is often increased (Fig 12) At this stage the chondrons are as a rule large round or oval and contain up to ten or twelve chondrocytes which at adequate resolution are seen to be distended and vacuolated and to have a pyknotic central or eccentric nucleus Between such chondrons there are necrotic foci more or less distinctly outlining the contours of former chondrons (Fig 12) A similar cell pattern may be encountered in cartilages with only a few fissures and similar large chondrons are then situated in the immediate neighbourhood of the fissures Changes of the type described in the foregoing are seldom accompanied by morphological abnormalities in the subchondral bone Nor is there appreciable synovial membrane *proliferation or round* cell invasion of the capsule

Degree II In addition to the changes described under 'Degree I the articular cartilage begins to present regions of circumscribed necrosis and local or extensive substance losses (Figs 13 14) The subchondral bone — hitherto at most showing minor thickening of the bone plate and cancellous trabeculae and occasional small regions of connective tissue *proliferation—now enters the picture and has conspicuous changes The marrow spaces are remarkably large* in some regions while in others they are markedly constricted and separated by thick trabeculae Vascularized connective tissue from the subchondral marrow spaces invades the base of

preserved cartilage portions and, via fibrocartilage, may give rise to formation of new bone so that varying portions of the subchondral bone plate are raised above its original level (Figs 14, 15, 16)

Opposite necrotic regions or substance losses in the articular cartilage the subchondral bone plate may have large defects which are either penetrated by vascularized connective tissue from enlarged subchondral marrow spaces or plugged by necrotic cartilage or bone (Figs 14 15) The synovial and fibrous layers of the joint capsule are no longer clearly demarcated and small deposits of new bone are present in the capsular attachments (Fig 18 b) Morphological changes of Degree II are not accompanied by round cell invasion of the capsule, nor by anything resembling pannus formation due to synovial tissue proliferation along the cartilage border

Degree III In the most advanced stages the micromorphology of the lumbar synovial joints is completely reorganized The subchondral marrow spaces are almost eradicated and replaced by large cavities containing connective tissue The latter is avascular centrally and anything from poor in vessels to typically hypervascularized peripherally The cavities are separated by large regions of closely spaced, thickened bone trabeculae (Fig 17) Isolated bone pieces are occasionally embedded in the connective tissue Large regions of the articular cartilage are now completely destroyed or replaced by connective tissue fibrocartilage or new bone deposited on the original subchondral bone plate The capsular attachment in the dorsal part of the joint is the site of large osteophytes whose marrow spaces communicate with those in the subchondral bone (Fig 6) But as in previous stages, there are only minor abnormalities in the insertion of ligamentum flavum The changes in ligamentum flavum rather take the form of metaplasia to chondral or osseous tissue locally in the zone where it meets articular cartilage subchondral bone and synovial tissue (Fig 5) Here osteophytes having blood vessels and marrow spaces that communicate with those in the subchondral bone are rarely seen

Comment

In addition to what the literature tells us about the normal microscopic anatomy of the lumbar synovial joints (cf p 9) the present investigation disclosed other facts about the micromorphology of the articular cartilage subchondral bone and joint capsule of these joints which are essential for the grading of any morphological changes in them Thus only in the central parts of the cartilage can tangential transitional and radial zones be distinguished from the disposition of the chondrons The calcified zone next to the subchondral bone plate is of uniform thickness and into it intrude so called vascular buds on the bone plate (cf Holmdal and Ingel

mark 1950 1951) In the ventral part of the articular process the part where ligamentum flavum inserts the subchondral bone fairly often exhibits somewhat thickened cancellous trabeculae Owing to non uniform growth of the articular processes the capsular attachment along the dorsal aspect of the joint is often more or less heavily marked even when the joint is micromorphologically normal

The morphological changes exhibited by the lumbar synovial joints could not be ascribed to either specific or unspecific inflammations in any of the examined spines Nor was there any evidence of other pathological conditions capable of affecting articular cartilage bone or connective tissue Moreover the morphological changes in these joints were all compatible with and included all the features of, the classical picture of osteoarthritis of the extremital joints The observed morphological changes in the lumbar synovial joints were accordingly interpreted as osteoarthritic *manifestations*

The osteoarthritic changes in the lumbar *synovial joints progressed with* age from mild to grave and lacked clearly demarcated stages

Between the ages of 30 and 45 years the osteoarthritic changes were as a rule mild and confined to the articular cartilages These had an irregular cell pattern owing to local cell proliferation a fibrillated inter cellular substance and a cracking surface At higher ages the cartilage surface became more and more broken up by these cracks and fissures appeared deeper in the cartilage whose calcified zone was thickening These changes gradually turned into more conspicuous defects in the cartilage such as necrosis and substance losses At this stage usually seen only after age 45 degenerative phenomena dominated the morphological picture of the articular cartilage

From 45 to 60 years of age—when the articular cartilages exhibited necrosis and substance losses comparatively often—osteoarthritic changes also appeared in both the subchondral bone and the joint capsule As in the extremital joints the changes now included restorative processes leading to formation of new bone which resulted in remodelling of the subchondral bone plate and the development of marginal osteophytes Concomitantly the loose synovial tissue in the joint capsule was trans formed into fibrous connective tissue

Around and after the age of 60 years the osteoarthritic changes often gave the impression of having completely reorganized the micromorpho logical appearance of the joints The articular cartilages exhibited extensive *necrotic regions* while other regions had been replaced by connective tissue fibrocartilage or new bone deposited on the original subchondral bone plate The subchondral bone was now the site of large cavities con taining connective tissue with anything from a few to abundant blood

vessels Between these cavities there were sclerotic regions where the cancellous trabeculae were thickened and closely spaced In the capsular attachments there were large marginal osteophytes whose marrow spaces were continuous with the subchondral marrow spaces

Those histological changes which are encountered in the lumbar synovial joints at a systematic histological examination of spines from average autopsy cases of different ages evidently constitute various degrees of osteoarthritic lesions The micromorphological appearance of these changes in the lumbar synovial joints is in complete agreement with that described in the literature with respect to osteoarthritic changes in the extremital joints (Nichols and Richardson, 1909, Pommer 1913, 1927 Lang, 1924, Harrison, Schajowicz and Trueta, 1953 Lloyd-Roberts, 1955 etc) The order of appearance and topography of the changes in the articular cartilage, subchondral bone and joint capsule during the course of osteoarthritis of the lumbar synovial joints are similar to those characterizing osteoarthritis of the extremital joints (Pommer, 1923, 1927, Heine, *1926 Harrison, Schajowicz and Trueta, 1953 etc) Accordingly osteoarthritis* of the lumbar synovial joints cannot morphologically be distinguished from osteoarthritis of the extremital joints

PLATES

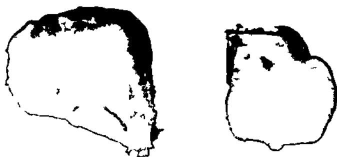
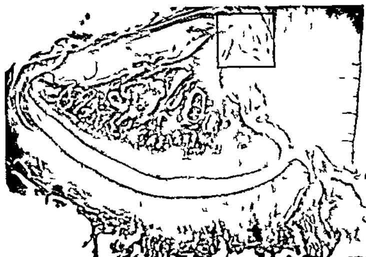


Fig 3 Synovial joint facets with gross cartilage changes The left facet shows a cartilage defect over 1 millimetre broad along its entire length (Left L_5—S_1 joint from male 24 years)



Fig 4 Relations between joint capsule and mamillary process Arrow on the left points to superior articular process with mamillary process and capsular attachment thereon On the right towards ligamentum flavum the subchondral bone exhibits somewhat thicker cancellous trabeculae than it does nearer the mamillary process (Right L_{3-4} joint Case 8 male 21 years × 3 5)



5 a



5 b

Fig 5 a New bone formation where ligamentum flavum inserts on inferior articular process (Right L_{4-5} joint Case 53 male 56 years x 3 5) b Detail of area marked in Fig 5 a Outside the articular process proper one sees a small region with osseous tissue embedded in fibrocartilage (x 100)



Fig 6 Joint with osteophytes On the right adjacent to the capsular attachments on the dorsal aspect of the joint osteophytes are present whose marrow spaces communicate with those in the articular processes The osteophyte on the inferior (convex) articular process is considerably larger than that on the superior (concave) articular process (Right L_{2-} joint Case 68 male 34 years x 5)



A



B



C



D

Fig. 7 Gross disc changes A=Grade 0 (Case 95 male 12 years L_5—S_1) B=Grade 1 (Case 93 male 40 years L_5—S_1) C=Grade 2 (Case 39 male 62 years L_{4-5}) D=Grade 3 (Case 69 male 46 years L_5—S_1)



Fig 8 Ossification of articular processes during growth The dorsal aspect of the joint with joint capsule appears on the right The inferior articular process shows enchondral ossification towards the capsular tissue (Left L_{3-4} joint from male 14 years x 7)



Fig 9 Joint with out turned facets In the dorsal part of the joint facing left the joint facets seem to be turned outwards owing to the marked indrawing of the capsular attachments (Right L_{1-} joint Case 9 female 24 years x 3 5)



A



B



C



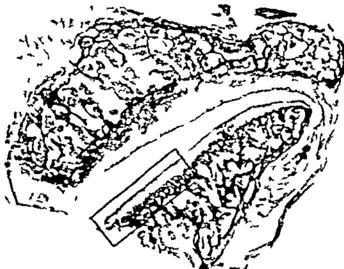
D

Fig. 7 Gross disc changes A=Grade 0 (Case 95 male 12 years L_5–S_1) B=Grade 1 (Case 93 male 40 years L_5–S_1) C=Grade 2 (Case 99 male 62 years L_{4-5}) D=Grade 3 (Case 69 male 46 years L_5–S_1)



10 c

Fig 10 a Survey view of joint without distinct morphological chan es The dorsal aspect of the joint and joint capsule appear on the left and its ventral aspect with ligamentum flavum on the right (Left L_{4-5} joint Case 9 male 30 years x 2 5) b Detail of central joint region (x 16) c Detail of dorsal aspect where the articul r cartilage *is seen to lack radially disposed chondrons (x 20)*



11 a



11 b

Fig 11 a Survey view of joint with incipient cartilage changes in the inferior joint facet (Left L_{3-4} joint Case 11 male 30 years x 3 5) b Detail of area outlined in Fig 11 a The cartilage exhibits fibrillation of the intercellular substance and basally remarkably large chondrons composed of 10—12 chondrocytes (x 56)



12 a



12 b

Fig. 12 a Articular cartilage with fissure formations on the left the calcified zone is markedly thickened (Right L_{4-5} joint Case 59 male 37 years x 20) b Detail of uncalcified articular cartilage in Fig 12 a The chondrons are remarkably closely spaced and the chondrocytes present all transitions between rather distinct demarcations to *amorphous or vacuolated appearances (x 1?0)*



13 a



13 b

Fig. 13 a Surv   iew of joint whose articular cartilage in marked area seems impressed into the sub ndral bone plate (Right joint Case 39 female 51 years x 3.5) b *Detail of ar   Fig. 13 a* Necrotic foci surrounded by comparatively well preserved chon   n the intermediate and deep layers of the cartilage (x 80)



14 a



14 b

Fig 14 a. Survey view of joint whose convex facet has large areas where articular cartilage is missing Subchondral changes in the area outlined have no counterpart in the subchondral bone of the concave facet (Right L_{3-4} joint Case 55 male 49 years × 3.5) b Detail of subchondral bone in area marked in Fig 14 a The marrow spaces are filled with rather poorly vascularized connective tissue (× 70)



13 a



13 b

Fig 13 a Survey view of joint whose articular cartilage in marked area seems impressed into the subchondral bone plate (Right L_{4-5} joint Case 39 female 51 years × 35) b Detail of area marked in Fig 13 a Necrotic foci surrounded by comparatively well preserved chondral [illegible] in the intermediate and deep layers of the cartilage (x 80)



Fig 16 Joint facet in whose cartilage new bone is forming and with the marrow spaces partly occupied by moderately vascularized connective tissue (Left L_{4-5} joint Case 25 male 69 years x 16)



17 a



17 b

Fig 17 a Joint facet whose subchondral bone exhibits alternately thickened cancellous trabeculae and comparatively large marrow spaces full of connective tissue which in parts is rather rich in vessels (Right L_5—S_1 joint Case 60 male 60 years × 15) b Another part of the facet illustrated in Fig 17 a Connective tissue from the subchondral marrow space fills a defect in the subchondral bone plate and in the overlying cartilage which is rather like fibrocartilage in appearance (× 72)

Fig 18 a Joint with a practically normal chondral cell pattern on the convex facet and marked cell proliferation in the cartilage on the concave facet (Left L_{2-3} joint Case 39 female 51 years × 20) b Detail of the capsular attachment on the concave facet of the joint in Fig 18 a The synovial and fibrou capsular layers are indistinctly demarcated owing to an ipient r t t suc transformation of the synovial membrane

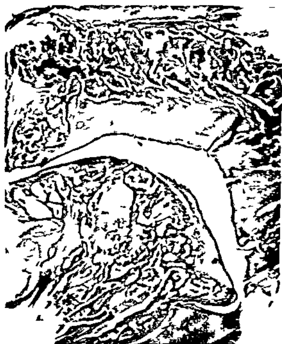


18 a





Fig 19 Joint whose concave facet has a cartilage with an isolated defect A discontinuity in the subchondral bone plate immediately beneath this defect is filled with connective tissue (Right L_{4-5} joint Case 32 female 42 years x 15)



20 a



20 b

Fig 20 a. Survey view of joint with advanced changes in the subchondral bone of the convex facet only (Left L_5—S_1 joint Case 91 female, 47 years x 2 5) b Detail of the convex facet of the joint in Fig 20 a Parts of the articular cartila e show marked thinning and the marrow spaces in the underlying bone contain remarkably fibrous con nective tissue (x 15)

TABLE 2

Significant mean score differences between corresponding joint facets in male and female lumbar spines within age groups. The sex with the highest mean is denoted by the symbol for that sex. Dashes indicate no significant difference. (Tested by Stundent's t test.)

A a. Cell pattern

Age groups		26—35		36—45		46—55		56—65		> 65 years	
Joint facets		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L_{1-2}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	♂
L_{2-3}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{3-4}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{4-5}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_5-S_1	sup	♂	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—

A b. Intercellular subtance

Age groups		26—35		36—45		46—55		56—65		> 65 years	
Joint facets		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L_{1-2}	sup	—	—	—	—	—	—	—	—	—	—
	inf	○	—	—	—	—	—	—	—	○	—
L_{2-3}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{3-4}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{4-5}	sup	—	—	—	—	○	♀	—	—	—	—
	inf	—	—	—	—	♀	—	—	—	—	—
L_5-S_1	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—

scoring 2 points was considerably higher at these ages than before age 45. Whereas the mean frequency of such facets per spine did not differ significantly from zero before age 45 it amounted to 21.9±7.8 † per cent after that age (Table 5 a).

The age groups 46—55 and over 65 years were the only ones in which the segmental mean score on corresponding joint levels significantly exceeded that in the preceding age group (Table 3) namely on the L_{3-4} and L_{4-5} levels in the former case and on all levels except L_5-S_1 in the latter. The same applied on all joint levels to the 46—55 years group compared with 20—25 years group and also to the group over 65 years compared with the 36—45 years group (Table 4).

† $\pm t \cdot S_{\bar{x}}$

TABLE 2 (cont)

B Calcified layer

Age groups		26–35		36–45		46–55		56–65		> 65 years	
Joint facets		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L_{1-2}	sup	♀	–	–	–	–	–	–	–	–	–
	inf	♀	–	–	–	–	–	–	–	–	–
L_{2-3}	sup	–	–	–	–	–	–	–	–	o	–
	inf	–	–	–	–	–	–	–	–	–	–
L_{3-4}	sup	–	–	–	–	–	–	–	–	–	–
	inf	–	–	–	–	–	–	–	–	–	–
L_{4-5}	sup	–	–	–	–	–	–	–	–	–	–
	inf	–	–	–	–	–	–	–	–	–	–
L_5-S_1	sup	♂	–	–	–	–	–	–	–	–	–
	inf	–	–	–	–	–	–	–	–	–	–

C. Subchondral bone

Age groups		26–35		36–45		46–55		56–65		> 65 years	
Joint facets		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L_{1-2}	sup	♀	–	–	–	–	–	–	–	–	–
	inf	ˇ		–	♂	–	–	–	–	–	–
L_{2-3}	sup	–	–	–	–	–	–	–	–	–	–
	inf	–	–	♀	–	–	–	–	–	–	–
L_{3-4}	sup	–	–	–	–	o	–	♀	–	–	–
	inf	–	–	–	–	–	–	–	–	–	–
L_{4-5}	sup	–	–	–	–	–	–	–	–	–	–
	inf		–	–	–		–	–	–	–	–
L_5-S_1	sup	–	–	♀	–	–	–	–	–	–	–
	inf	–	–	–	–	–	–	–	–	–	–

D Capsular attachment

Age groups		26–35		36–45		46–55		56–65		> 65 years	
Joint facets		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L_{1-2}	sup	–	–	–	–	–	–	–	♀	–	–
	inf	–	–	–	–	–	♀	–	♀	–	–
L_{2-3}	sup	–	–	–	♀	–	♀	–	♀	–	–
	inf	–	–	–	–	–	–	–	–		
L_{3-4}	sup	–	–	–	–	–	–	–	–	–	
	inf	–	–	–	–	–	–	–	–	–	–
L_{4-5}	sup	–	–	♂	–	–	–	–		–	–
	inf	–	–	–	–	–	–	–	–	–	–
L_5-S_1	sup	♂	–	–	–	–	–	–		–	–
	inf	–	–	–	–	–	–	–	–	–	–

TABLE 2

Significant mean score differences between corresponding joint facets in male and female lumbar spines within age groups. The sex with the highest mean is denoted by the symbol for that sex. Dashes indicate no significant difference (Tested by Stundent's t test.)

A a Cell pattern

Age groups		26—35		36—45		46—55		56—65		> 65 years	
Joint facets		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L_{1-2}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	♂
L_{2-3}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{3-4}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{4-5}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_5-S_1	sup	♂	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—

A b Intercellular subtance

Age groups		26—35		36—45		46—55		56—65		> 65 years	
Joint facets		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L_{1-2}	sup	—	—	—	—	—	—	—	—	—	—
	inf	♀	—	—	—	—	—	—	—	♀	—
L_{2-3}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{3-4}	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—
L_{4-5}	sup	—	—	—	—	♀	♀	—	—	—	—
	inf	—	—	—	—	♀	—	—	—	—	—
L_5-S_1	sup	—	—	—	—	—	—	—	—	—	—
	inf	—	—	—	—	—	—	—	—	—	—

scoring 2 points was considerably higher at these ages than before age 45. Whereas the mean frequency of such facets per spine did not differ significantly from zero before age 45, it amounted to 21.9 ± 7.8 † per cent after that age (Table 5 a).

The age groups 46—55 and over 65 years were the only ones in which the segmental mean score on corresponding joint levels significantly exceeded that in the preceding age group (Table 3), namely on the L_{3-4} and L_{4-5} levels in the former case and on all levels except L_5-S_1 in the latter. The same applied on all joint levels to the 46—55 years group compared with 20—25 years group and also to the group over 65 years compared with the 36—45 years group (Table 4).

† ± t $S_{\bar{x}}$

Of those joint facets with cartilages scoring more points for inter cellular substance than for cell pattern about half occurred on the L_{1-2} and L_{2-3} levels The basic scoring sheets for these facets disclosed that practically all had displayed fibrillation of the intercellular substance while a slightly deviating cell distribution in the cartilage was deemed normal for the cartilages on these levels (cf p 27) Roughly 5 per cent of the facets exhibited losses of cartilage substance without concomitant necrosis (Fig 19)

Subchondral Bone (C) Up to the age of 45 years there was a rising frequency of minor changes such as small areas with thickened cancellous trabeculae and occasional marrow spaces with connective tissue prolifera tion (Fig 14) in other words a score of 1 point for the joint facet (Fig 27) At these ages the segmental mean score on the L_{1-2} level did not differ significantly from zero but it did so in the L_{3-4} level in the 36—45 years group as well as on the L_{2-3} L_{4-5} and L_5-S_1 levels in the 26—35 years group (Fig 24 Table 20) Before age 45 no segmental mean score ex ceeded 2 points Thereafter joints occurred with more advanced changes in the subchondral bone for example extensive sclerosis marrow spaces con- taining connective tissue and ingrowth of more or less vascularized con nective tissue into the basal parts of the articular cartilage from neigh bouring marrow spaces by way of abnormal defects in the subchondral bone plate (Fig 17) The mean frequency per spine of facets with such grave changes in the subchondral bone scoring 2 points differed signi ficantly from zero at ages over 45 years and was $7\ 6 \pm 3\ 6$† per cent (Table 5 a)

The segmental mean score for the L_{4-5} level of the lumbar spine in all age groups was significantly higher than for the corresponding level in the preceding age group (Table 3) the 36—45 years group being an exception to this rule The mean scores for the other levels were only in the age groups 36—45 46—55 or >65 years significantly higher than for the corresponding levels in the preceding age group At ages over 55 years the segmental mean scores for all levels significantly exceeded the cor responding mean scores at ages up to 35 years (Table 4)

Capsular Attachments (D) Along the joint margin on the transition from hyaline cartilage to fribrocartilage and where the capsule attaches to adjacent bone only minor changes such as fibrosis of synovial tissue or small osteophytes were encountered before age 45 Between 20 and 45 years of age therefore the segmental mean score was at most 2 points on

† $\pm t\ s_{\bar{x}}$

TABLE 5 a

Mean frequency per lumbar spine of joint facets showing osteoarthritic changes of grade 2

		Age 20—45 years		Age > 45 years	
		N	M ± t S$\bar{x}$	N	M ± t S$\bar{x}$
Cell pattern	(A a)	40	0 7 ± 0 8 %	38	21 9 ± 7 8 %
Intercellur substance	(A b)	40	1 3 ± 0 7 %	38	28 1 ± 9 2 %
Calcified cartilage	(B)	40	0 5 ± 0 3 %	38	9 5 ± 6 6 %
Subchondral bone	(C)	40	0 2 ± 0 4 %	38	7 6 ± 3 6 %
Capsular attachment	(D)	40	0 3 ± 0 6 %	38	9 3 ± 3 2 %

TABLE 5 b

Frequency of lumbar spines above 45 years with some joint facets showing osteoarthritic changes of grade 2

		Number of lumbar spines					
Number of joint facets on each spine with grade 2		0	1—2	3—6	7—8	9—12	> 12
Cell pattern	(A a)	12	10	10	0	4	2
Intercellur substance	(A b)	10	7	9	2	6	4
Calcified cartilage	(B)	26	5	4	0	3	0
Subchondral bone	(C)	21	9	7	1	0	0
Capsular attachment	(D)	21	10	6	1	0	0

TABLE 5 c

Mean frequency per lumbar spine above 45 years with joint facets showing extensive cartilage changes and with joint facets showing extensive bone changes

	N	M ± t S$\bar{x}$
Extensive cartilage changes (a = 2 and b = 1 a = 1 and b = 2 or a = 2 and b = 2)	38	34 7 ± 8 2 %
Extensive bone changes (C = 2 and D = 1 C = 1 and D = 2 or C = 2 and D = 2)	38	13 4 ± 4 4 %

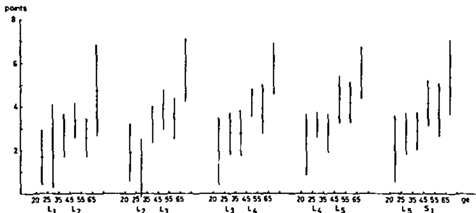


Fig 21 Mean segmental scores with confidence limits within age groups for osteoarthritic changes in the cell pattern of the articular cartilage of lumbar synovial joints (cf Table 20)

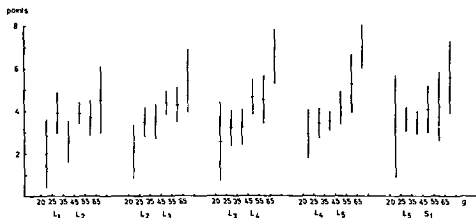


Fig 22 Mean segmental scores with confidence limits within age groups for osteoarthritic changes in the intercellular substance of the articular cartilage of lumbar synovial joints (cf Table 20)

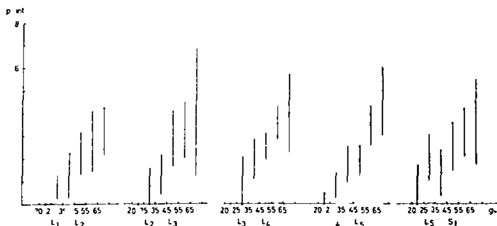


Fig 23 Mean segmental scores with confidence limits within age groups for osteoarthritic changes in the calcified portion of the articular cartilage of lumbar synovial joints (cf Table 20)

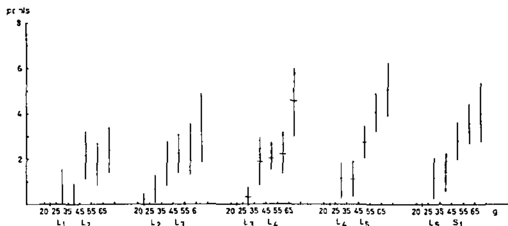


Fig 24 Mean segmental scores with confidence limits within age groups for osteoarthritic changes in the subchondral bone of lumbar synovial joints (cf Table 20)

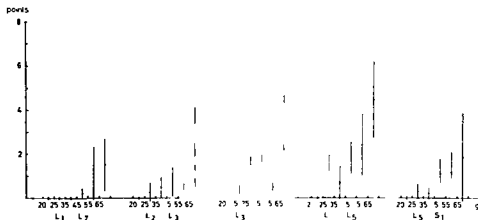


Fig 25 Mean segmental scores with confidence limits within age groups for osteoarthritic changes in the capsular attachments of lumbar synovial joints (cf Table 20)

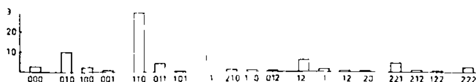


Fig 26 Relative frequencies of joint facets with different combinations of the three digit number for the degree of osteoarthritic changes in cell pattern (A a) intercellular substance (A b) and calcified portion (B) of the articular cartilage

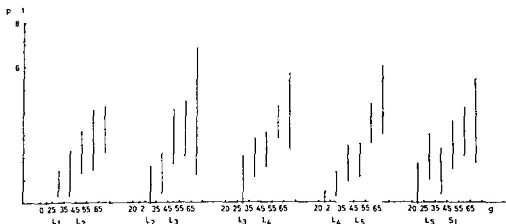


Fig 23 Mean segmental scores with confidence limits within age groups for osteoarthritic changes in the calcified portion of the articular cartilage of lumbar synovial joints (cf Table 20)

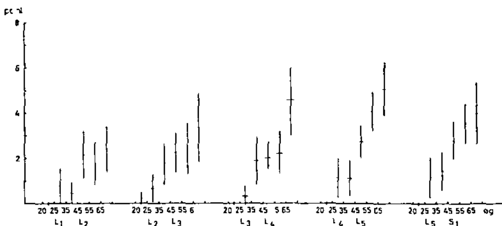


Fig 24 Mean segmental scores with confidence limits within age groups for osteoarthritic changes in the subchondral bone of lumbar synovial joints (cf Table 20)

Topographic Relations (Table 6)

Intrasegmental differences

The two facets of the same synovial joint occasionally exhibited differences in the degree of osteoarthritic changes Indeed one facet might exhibit a sensibly normal cell pattern in the articular cartilage and the other pronounced cell proliferation (Fig 18 a) A higher degree of cell pattern abnormality was shown by one of the facets in 4 4 ± 2 2 per cent of the examined joints The corresponding difference for the inter cellular substance was 6 7 ± 2 7 per cent The usual difference in the latter case was that one of the cartilages displayed fringing only and the other fringing plus extensive substance losses (Fig 19) There were even substantial differences in the appearance of the calcified cartilage zone between the superior and inferior surfaces of 3 5 ± 2 0 per cent of the joints In 5 1 ± 2 4 per cent of the joints one facet had negligible subchondral changes and the other facet displayed markedly thickened cancellous trabeculae and marrow spaces filled with connective tissue (Figs 19 20) The most common discrepancy was that osteophytes were lacking or negligible on one facet and comparatively large on the other (Fig 6) This was so in 10 8 ± 3 3 per cent of the joints These differences between the two facets in the same joint were distributed rather uniformly on the lumbar levels and on the right and left sides The superior joint facet had the higher degree of osteoarthritic changes as often as the inferior Furthermore examinations of the confidence limits for mean facet scores within age groups revealed no systematic topographic differences between facets

Intersegmental differences

Considering that the osteoarthritic changes tended to affect the synovial joints on the lower levels of the lumbar spine sooner than the joints on the upper levels (cf p 57) differences in the degree of osteoarthritic changes were analyzed between segments without paying regard to age or sex but including only such spines in which all facets could be examined

Articular cartilage The cell pattern exhibited significant intersegmental mean differences when scores for the three lower segments were compared with those of the two upper segments of the lumbar spine Significant mean differences for intercellular substance were found between the L_{1-2} seg ment and each of the segments below it Conversely the calcified zone displayed no significant intersegmental mean differences between the segmental scores in the degree of osteoarthritic lesions (Table 6 Figs 28, 29 30)

The maximum mean differences for cell pattern and intercellular substance were 0 87 ± 0 56 and 0 78 ± 0 55 points respectively, both occur-

TABLE 6

Mean differ nces between segmental scores (cf p 30) for osteoarthritic changes
ie differences apply to all lumbar spines over 20 years of age with complete sets of synovial joints)

		A.a *Cell pattern*		A b *Intercellular substance*		B *Calcified layer*		C. *Subchondral bone*		D *Capsular attachment*
nts ared	N	$M \pm t\ S_{\bar{x}}$	N	$M \pm t\ S_{\bar{x}}$	N	$M \pm t\ S_{\bar{x}}$	N	$M \pm t\ S_{\bar{x}}$	N	$M \pm t\ S$
·L_{1-2}	53	0 26 ± 0 45	57	0 53 ± 0 45	58	0 19 ± 0 75	63	0 56 ± 0 50	61	0 40 ± (
·L_{2-3}	53	0 55 ± 0 44	57	0 23 ± 0 36	58	0 19 ± 0 42	63	0 22 ± 0 40	61	0 31 ± (
·L_{3-4}	53	0 06 ± 0 41	57	0 03 ± 0.58	58	0 05 ± 0 40	63	0 43 ± 0 41	61	0 61 ± (
–L_{4-5}	53	–0 07 ± 0 41	57	–0 19 ± 0 50	58	0 10 ± 0 47	63	–0 08 ± 0 45	61	–0 85 ± (
·L_{1-2}	53	0 81 ± 0 64	57	0 75 ± 0 49	58	0 38 ± 0 50	63	0 78 ± 0 48	61	0 82 ± (
·L_{1-2}	53	0 87 ± 0 56	57	0 78 ± 0 55	58	0 43 ± 0 50	63	1 21 ± 0 52	61	1 38 ± (
–L_{1-2}	53	0 80 ± 0 56	57	0 56 ± 0 54	58	0 53 ± 0 56	63	1 13 ± 0 58	61	0 56 ± (
·L_{2-3}	53	0 60 ± 0 38	57	0 26 ± 0 44	58	0 24 ± 0 55	63	0 65 ± 0 52	61	0 93 ± (
–L_{2-3}	53	0 54 ± 0 52	57	0 07 ± 0 46	58	0 33 ± 0 51	63	0 57 ± 0 58	61	0 05 ± (
–L_{3-4}	53	0 02 ± 0 56	57	–0 16 ± 0 50	58	0 12 ± 0 51	63	0 35 ± 0 56	61	–0 26 ± (

ber of lumbar spines examined

n difference of segmental scores

ring between L_{4-5} and L_{1-2} segments Notably however, only 27 of the 53 spines examined had higher cell pattern scores for the lower than for the upper segments The latter spines included 8 with a score difference of 1 point 12 with a score difference of 2—3 points and 7 with a score difference of 4 or more points between the lower and the upper segments These 7 spines had cartilage necrosis confined to joint facets only in the three lower segments

The intercellular substance score for the three lower segments exceeded that for the two upper segments in 36 of 57 spines a difference of 2 points or more being present in 15 of these lumbar spines In 6 of these 15 spines the difference was due to the fact that facets in the three lower segments exhibited losses of cartilage substance (i e a score of 2 points per facet) whereas the facets in the two upper segments merely presented intercellular substance fibrillation (i e a score of 1 point per facet)

Subchondral Bone Significant intersegmental mean differences for the degree of osteoarthritic changes in the subchondral bone were found when segmental scores of L_{1-2} were compared with those for each segment

below it Moreover, segment L_{4-5} exhibited significant mean differences from segments L_{2-3} and L_{3-4} (Table 6 Fig 31)

The highest intersegmental mean difference was present between L_{4-5} and L_{1-2} segments with 1 21 ± 0 52 points and the next highest between L_5-S_1 and L_{1-2} segments with 1 13 ± 0 58 points

The scores for any of the three lower segments exceeded that for the two upper segments in 45 of the 63 lumbar spines examined with respect to the degree of osteoarthritic changes in the subchondral bone In the majority of these 45 spines 2 or three facets in the lower segments had higher scores than the facets of the two upper segments In 8 spines a difference of 2 points or more was recorded between the lower and the upper segments the cause being that one or a few facets in the three lower segments exhibited extensive subchondral sclerosis and marked connective tissue proliferation in the marrow spaces (a facet score of 2 points) while the facets in the two upper lumbar segments merely showed minor subchondral changes (i e a facet score of 1 point)

Capsular Attachments In regard to the degree of osteoarthritic changes in the capsular attachments the L_{4-5} segment exhibited significant mean differences from any other segment in the lumbar spine except that for the L_5-S_1 segment Furthermore significant mean differences were found between each of the segments L_{2-3} L_{3-4} and L_5-S_1 on the one hand and the L_{1-2} segment on the other (Table 6 Fig 32)

The maximum intersegmental mean difference was 1 38 ± 0 50 points and occurred between L_{4-5} and L_{1-2}

A segmental score difference of 3 points or more was noted in 10 of 61 spines for the L_{4-5} segment compared with other segments In these 10 spines the L_{4-5} segments either was the only ones in the lumbar spine with osteophytes in the capsular attachments or it had conspicuous osteophytes while the joints in the other segments had only small osteophytes

None of the spines with intersegmental score differences for articular cartilage subchondral bone or capsular attachments exhibited evidence in the roentgenograms of marked joint asymmetry in the lower segments

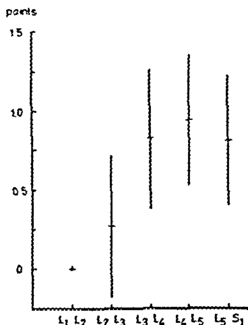


Fig 28 Mean differences between segmental scores for osteoarthritic changes in the cell pattern (A a) of the articular cartilage in the synovial joints

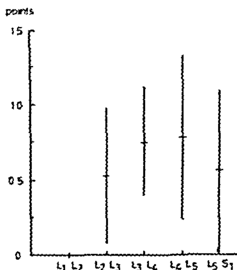


Fig 29 Mean differences between segmental scores for osteoarthritic changes in the intercellular substance (A b) of the articular cartilage in the synovial joints

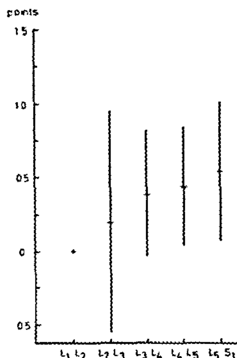


Fig 30 Mean differences between segmental scores for osteoarthritic changes in the calcified portion (B) of the articular cartilage in the synovial joints

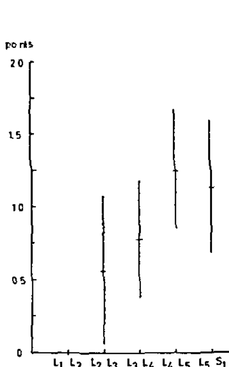


Fig 31 Mean differences between segmental scores for osteoarthritic changes in the subchondral bone (C) of the synovial joints

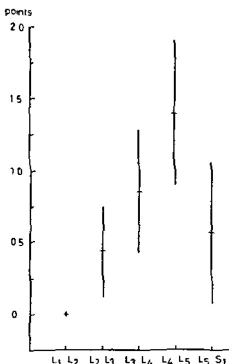


Fig 32. Mean differences between segmental scores for osteoarthritic changes in the capsular attachments (D) of the synovial joints

Fig 28—32 Mean differences between segmental scores for osteoarthritic changes in all lumbar spines over 20 years of age with complete sets of synovial joints Interpolation for any two segm nts gives their m an difference The confidence limits refer to the differences obtained by comparing any segment with the next higher segment (cf Table 6)

and subchondral bone of one facet exhibited changes of higher degree than the other in some 5 per cent of the joints examined while the capsular attachment did so in about 10 per cent of the joints Such differences between ipsiarticular facets were distributed on all the lumbar synovial joints without showing any predilection for the superior or inferior facet, the left or right joint in the same segment or any of the lumbar segments For some reason therefore, the development of the osteoarthritic changes in one facet may lag behind that in the other facet of the same joint

When all the lumbar spines regardless of age and sex were analyzed with respect to intersegmental differences in the degree of osteoarthritic changes significant differences appeared This was the case for the cell pattern of the articular cartilage between the three lower lumbar segments on the one hand and the two upper segments in the other The degree of changes in the intercellular substances differed significantly for the three lower *segments only compared with the* L_{1-2} segment *These significant* intersegmental differences in cell pattern and intercellular substance could be accounted for mainly by necrosis and substance losses in the articular cartilage of one or more facets in the three lower segments while the L_{1-2} and L_{2-3} facets had articular cartilages exhibiting merely cell proliferation and fibrillation of the intercellular substance No intersegmental differences appeared for the calcified zone of the articular cartilage

In principle the degrees of osteoarthritic changes in the subchondral bone displayed similar intersegmental differences as the articular cartilage except that the differences were more accentuated for the subchondral bone Thus the mean score for subchondral osteoarthritic changes for the facets in the L_{4-5} segment was significantly higher than the corresponding score for any segment craniad to it Extensive subchondral sclerosis and an abundance of more or less highly vascularized connective tissue in the marrow spaces confined to the facets in the three lower lumbar segments constituted the main contributory factor to these differences

Changes in the form of osteophytes in the capsular attachments showed a *higher mean degree in the* L_{4-5} *segment than in any other lumbar segment.* This predominance can be accounted for to a large extent by the fact that every fifth spine had markedly larger osteophytes here than elsewhere

The level of the joints within the lumbar spine is thus a factor of significance for the degree of osteoarthritic changes This contention is borne out by the fact that the more extensive the changes in the structures of the joint the greater were the intersegmental differences In the lower segments of the lumbar spine especially the L_{4-5} segment the osteoarthritic changes consequently seem to be dependent on one or more factors in addition to age

CHAPTER 6

Osteoarthritis in Synovial Joints, Disc Degeneration and Marginal Vertebral Osteophytes in the Lumbar Spine

Osteoarthritis (Tables 7 8 9 10)

Osteoarthritis in lumbar synovial joints was considered present in any segment where at least one synovial joint facet exhibited both chondral and subchondral changes (Fig 55) Only necrosis and substance losses were accepted as reliable chondral changes but even minor sclerosis and connective tissue proliferation in the subchondral bone as well as small osteophytes in the capsular attachments were regarded as reliable subchondral changes (Aa = 2, Ab = 2 C = 1 or 2 D = 1 or 2 cf p 27)

The complete series of lumbar spines included none with osteoarthritis before the age of 25 years. Between 26 and 45 years 40 0 ± 11.0 per cent (8 of 20) lumbar spines exhibited osteoarthritis. In 3 of these spines the synovial joints in the L_{1-2} segment were affected, in 4 those in the L_{2-3} segment and in one those in the L_5—S_1 segment (Tables 7 8)

Over 45 years 90.3 ± 5.4 per cent (28 of 31) lumbar spines exhibited osteoarthritis of the synovial joints (Table 7) The frequency of spines with osteoarthritis on a particular level rose gradually from the L_{1-2} segment to the L_5—S_1 segment, the respective frequencies being 32.3 ± 8.4 and 64.3 ± 9.1 per cent (Table 8) The frequencies of L_{4-5} and L_5—S_1 segments with affected synovial joints were significantly higher than the frequencies of affected L_{1-2} and L_{2-3} segments. The same applies to the L_{3-4} segment compared with the L_{1-2} segment (Table 8)

TABLE 7

Absolute and relative frequencies of lumbar spines with osteoarthritis in at least one segment

	Osteoarthritis				
Age	N	n	%	S%	S% × 1.96
20—25 years	6	0	0	—	0 6%*
26—45 years	20	8	40 0	± 11 0	± 21 6
> 45 years	31	28	90.3	± 5 4	± 10 6

TABLE 8

Absolute and relative frequencies of osteoarthritis in separate lumbar spine segments

	Age 26–45 years					Age > 45 years				
	Osteoarthritis					Osteoarthritis				
Segments	N	n	%	S%	S% × 1.96	N	n	%	S%	S% × 1.96
L_{1-2}	23	3	13.0	± 7.0	± 13.7	31	10	32.3	± 8.4	± 16.5
L_{2-3}	27	4	14.8	± 6.9	± 13.5	36	14	38.9	± 8.1	± 15.9
L_{3-4}	21	0	0	—	(13.3 %)*	35	19	54.3	± 8.4	± 16.5
L_{4-5}	25	0	0	—	(11.3 %)*	33	19	60.6	± 8.4	± 16.5
L_5–S_1	23	1	0	—	(19.3 %)*	28	18	64.3	± 9.1	± 17.8

TABLE 9

Absolute and relative frequencies of lumbar spines over 45 years of age with osteoarthritis in *at least two adjacent segments*

	Osteoarthritis				
Segments	N	n	%	S%	S% × 1.96
L_{1-2} and L_{2-3}	28	5	17.9	± 7.3	± 14.3
L_{2-3} and L_{3-4}	32	11	34.4	± 8.4	± 16.5
L_{3-4} and L_{4-5}	30	14	46.7	± 9.1	± 17.8
L_{4-5} and L_5–S_1	25	13	52.0	± 9.7	± 19.0

TABLE 10

Absolute and relative frequencies of lumbar spines over 45 years of age with osteoarthritis in at least three segments

	Osteoarthritis				
Segments	N	n	%	S%	S% × 1.96
L_{1-2} L_{2-3} and L_{3-4}	28	4	14.3	± 6.6	± 12.9
L_{2-3} L_{3-4} and L_{4-5}	27	7	25.9	± 8.4	± 16.5
L_{3-4} L_{4-5} and L_5–S_1	24	15	37.5	± 9.8	± 19.2
Joint segments not adjacent	35	17	48.6	± 8.4	± 16.5

N = number of spines examined

n = number of examined spines showing osteoarthritis

* = estimated upper limit

Whereas osteoarthritis of the synovial joints was confined to a single segment in the ages up to 45 years, more than one segment was affected from the age of 46 years Thus of the total number of examined L_{1-2} and L_{2-3} segment pairs 17 9 ± 7 3 per cent were affected The corresponding figures for the segment pairs L_{2-3} and L_{3-4}, L_{3-4} and L_{4-5} as well as L_{4-5} and L_5—S_1 were 34 4 ± 8 4 46 7 ± 9 1 and 52 0 ± 9 7 per cent (Table 9) Osteoarthritis in 3 or more segments occurred in 48 6 ± 8 4 per cent of the lumbar spines over 45 years of age (Table 10)

All segments could be examined in 14 of the 28 lumbar spines over 45 years of age with osteoarthritis of the synovial joints A mere 6 of them (41 9 ± 12 4 %) exhibited osteoarthritis of the synovial joints in the L_{1-2} and/or L_{2-3} segments while 13 of them (92 9 ± 24 4 %) exhibited osteoarthritis in at least two of the segments L_{3-4} L_{4-5} and L_5—S_1

Disc degeneration (Tables 11 12)

In the present context disc degeneration was regarded gross changes of grades 2 and 3

Gross disc changes involving both nucleus pulposus and annulus fibrosus began to appear in the 20—25 years group (Table 11) Disc degeneration

TABLE 11

Frequency of intervertebral discs with gross changes of grades 0 1 2 or 3 (cf p 31) in separate lumbar spine segments

Age	20—25 years				26—35 years				36—45 years			
Grade	0	1	2	3	0	1	2	3	0	1	2	3
Segments												
L_{1-2}	3	6	1	0	3	10	2	0	1	16	0	0
L_{2-3}	4	4	2	0	4	11	0	0	2	13	2	0
L_{3-4}	4	5	1	0	6	7	2	0	3	11	3	0
L_{4-5}	3	2	4	1	4	8	2	1	3	7	7	0
L_5—S_1	4	3	3	0	1	8	4	2	0	9	6	2
Age	46—55 years				56—65 years				> 65 years			
Grade	0	1	2	3	0	1	2	3	0	1	2	3
Segments												
L_{1-2}	0	14	2	0	0	7	3	2	0	3	4	1
L_{2-3}	1	13	2	0	0	7	6	0	2	1	3	1
L_{3-4}	1	13	2	0	1	4	6	2	1	3	2	2
L_{4-5}	1	7	4	4	1	1	7	4	0	4	3	1
L_5—S_1	0	6	5	5	0	2	8	3	0	3	3	2

Significant intersegmental mean differences in the degree of osteophyte formation occurred between the L_{3-4} and L_{2-3} segments (Fig 35) Of 36 lumbar spines with osteophytes 5 had large osteophytes (grade 2 or 3) in the former segment and insignificant or no osteophytes (grade 0 or 1) in the latter

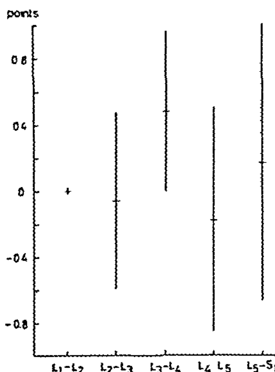


Fig 35 Mean differences between segmental scores for marginal osteophytes on the vertebral bodies in all lumbar spines over 20 years of age with osteophytes in at least one segment. Interpolation for any two segments gives their mean difference The confidence limits refer to the differences obtained by comparing any segment with the next higher segment.

Isolated Osteoarthritis (Table 14)

Regardless of age 25 of 46 lumbar spines with 5 complete segments had osteoarthritis in at least one segment 9 of them (36 4 ± 9 6 %) had at least one segment with osteoarthritis as the sole pathological change 5 being up to 45 years and 4 over 45 years

Isolated Disc Degeneration (Table 14)

Regardless of age 28 of 46 lumbar spines with 5 complete segments had disc degeneration in at least one segment In 8 of them (28 6 ± 8 6 %) all 20—45 years old, at least one segment exhibited disc degeneration as the only pathological condition

Isolated Marginal Osteophytes (Table 14)

Regardless of age 24 of 46 lumbar spines with 5 complete segments had osteophytes in at least one segment, but the condition was isolated in only one spine This occurred in the L_{3-4} segment and took the form of sharpening of the vertebral body margins

TABLE 14

Absolute and relative frequencies of lumbar spines with and without isolated disc degeneration osteoarthritis or marginal osteophytes in at least one segment The frequencies apply exclusively to complete lumbar spines with disc degeneration, osteoarthritis and/or marginal osteophytes in at least one segment

Age	20—45 years	> 45 years	> 20 years
Disc degeneration only	8	0	8 (28 6 ± 8 6 %)
Disc degeneration and marginal osteophytes or osteoarthritis	8	12	20 (71 4 ± 8 6 %)
Osteoarthritis only	5	4	9 (36 4 ± 9 6 %)
Osteoarthritis and disc degeneration or marginal osteophytes	3	13	16 (63 6 ± 9 6 %)
Marginal osteophytes only	1	0	1 (0 18 2 %)
Marginal osteophytes and disc degeneration or osteoarthritis	4	19	23 (95 7 ± 4 2 %)

* = estimated upper limit

The following analysis included only lumbar spines with 3 or more complete segments In the 20—45 years group this means that only 33 of the original 43 and over 45 years 31 of 43 spines could be included (Cf Table 15)

Intrasegmental Frequency Differences and Intercurrences (Tables 15, 16, 17, 18)

Significant frequency differences between osteoarthritis, disc degeneration and marginal osteophytes occurred only in the 20—45 years group In this age group the L_{4-5} and L_5—S_1 segments exhibited higher disc degeneration frequencies than frequencies of the other two conditions In the L_{4-5} segment 11 of 31 spines (35 5 ± 16 9 %) had disc degeneration while only one had marginal osteophytes and none osteoarthritis In the L_5—S_1 segment 11 of 29 spines exhibited disc degeneration (37 9 ± 17 6 %), the figures for marginal osteophytes and osteoarthritis being 2 and 1 spines respectively (Table 15)

In all segments disc degeneration and marginal osteophytes on the one hand as well as marginal osteophytes and osteoarthritis on the other were intercurrent oftener than one would expect of a random distribution the respective (product moment) correlation coefficients both varying between 0 3 and 0 5 (Tables 16, 17) Conversely, only the L_{2-3} and L_5—S_1 seg

TABLE 15

Absolute and relative frequencies of disc degeneration marginal osteophytes and osteoarthritis in separate lumbar segments

The frequencies apply exclusively to complete spinal joints

	Segment	N	Disc degeneration				Marginal osteophytes				Osteoarthritis			
			n	%	S %S	%×1 96	n	%	S %	S%×1 96	n	%	S %	S %×
	L_{1-2}	28	3	10 7	±5 8	±11 4	0	0	0	(10 2%)*	3	10 7	±5 8	±1
	L_{2-3}	30	3	10 0	±5 5	±10 8	1	3 3	0	(14 2%)*	4	13 3	±5 9	±1
	L_{3-4}	27	5	18 5	±7 4	±14 5	3	11 1	± 6 2	±12 2	0	0	0	(10 5
ars	L_{4-5}	31	11	35 5	±8 6	±16 9	1	3 2	0	(13 8%)*	0	0	0	(9 2
	L_5-S_1	29	11	37 9	±9 0	±17 6	2	6 8	± 4 7	± 9 2	1	3 4	0	(14 6
	L_{1-2}	28	8	28 6	±8 6	±16 9	10	35 9	± 9 1	±17 8	10	35 9	±9 1	±1
	L_{2-3}	31	10	32 3	±8 4	±16 5	9	29 1	± 8 2	±16 1	12	38 9	±8 8	±1
	L_{3-4}	31	10	32 3	±8 4	±16 5	16	51 6	± 9 0	±17 6	16	51 6	±9 0	±1
rs	L_{4-5}	29	19	65 5	±8 8	±17 2	10	34 1	± 8 8	±17 2	18	62 1	±9 0	±1
	L_5-S_1	25	16	64 0	±9 6	±18 8	13	52 0	±10 0	±19 6	15	60 0	±9 8	±1

* = estimated upper limit

ments exhibited intercurrence of disc degeneration and osteoarthritis oftener than one would expect of a random distribution the (product moment) correlation coefficient being 0 35 and 0 33 respectively (Table 18)

TABLE 16

Segmental intercurrence of disc degeneration and marginal osteophytes in the lumbar spine

	Segments				
	L_{1-2}	L_{2-3}	L_{3-4}	L_{4-5}	L_5-S_1
No of cases studied	56	67	56	60	54
No with disc degeneration	11	13	15	30	27
No with marginal osteophytes	10	10	19	11	15
No with intercurrent disc degeneration and marginal ostophytes	7	10	10	10	11
No with intercurrence expected from the nullhypothesis	1 97	3 81	4 41	5 50	7 22
χ^2 ($\chi^2_{0\,05} = 3\,84$)	15 90	14 95	11 40	7 11	6 35
Correlation coefficient r (product moment)	+ 0 54	+ 0 47	+ 0 45	+ 0 34	+ 0 35

TABLE 17

Segmental intercurrence of marginal osteophytes and osteoarthritis in the lumbar spine

	Segments				
	L_{1-2}	L_{2-3}	L_{3-4}	L_{4-5}	L_5-S_1
No of cases studied	56	57	56	60	54
No with marginal osteophytes	10	10	19	11	15
No with osteoarthritis	13	16	16	18	16
No with intercurrent marginal osteophytes and osteoarthritis	6	9	12	7	10
No with intercurrence expected from the null hypothesis	1 97	3 81	4 41	3	4 44
χ^2 ($\chi^2_{0\,05} = 3\,84$)	9 74	10 10	14 40	7 80	11 30
Correlation coefficient r (product moment)	+ 0 42	+ 0 42	+ 0 51	+ 0 36	+ 0 46

TABLE 18

Segmental intercurrence of disc degeneration and osteoarthritis in the lumbar spine

	Segments				
	L_{1-2}	L_{2-3}	L_{3-4}	L_{4-5}	L_5—S_1
No of cases studied	56	67	56	60	54
No with disc degeneration	11	13	15	30	27
No with osteoarthritis	13	16	16	18	16
No with intercurrent disc degeneration and osteoarthritis	5	9	7	8	12
No with intercurrence expected from the null hypotesis	2 55	4 18	4	9	8
χ^2 ($\chi^2_{0\ 05}$ = 3 84)	2 40	8 05	2 92	0 20	5 90
Correlation coefficient r (product moment)	+ 0 21	+ 0 35	+ 0 23	+ 0 01	+ 0 33

Intersegmental Frequency Differences and Intercurrences (Tables 15, 19)

Intersegmental significant frequency differences between osteoarthritis disc degeneration and marginal osteophytes occurred exclusively between 20 and 45 years of age Thus the L_{4-5} segment displayed a higher frequency of disc degeneration than the L_5—S_1 segment of marginal osteophytes or osteoarthritis The L_{4-5} segment displayed disc degeneration in 11 of 31 spines (35 5 ± 16 9 %) while the L_5—S_1 segment showed marginal osteophytes in 2 and osteoarthritis in 1 of 29 spines The latter segment had disc degeneration in 11 of 29 spines (37 9 ± 17 6 %) while the former exhibited marginal osteophytes in 1 and osteoarthritis in none of the 31 spines In addition to these significant differences the frequency of disc degeneration on each of the two lower segments exceeded the frequency of marginal osteophytes in the L_{1-2} or L_{2-3} segments (0 of 28 and 1 of 30 spines respectively) and the osteoarthritis (0 of 27) frequency in the L_{3-4} segment (Table 15)

A diffuse pattern of positive correlations appeared between disc degeneration in one segment and marginal osteophytes or osteoarthritis in another segment This should be considered in the light of the fact that each of the conditions osteoarthritis, disc degeneration and marginal osteophytes is present in adjacent segments more often than one would expect of a random distribution (Table 19) Owing to the aforementioned intra segmental correlations this pattern should therefore be interpreted as the result of mere numerical coincidences without biological significance

TABLE 19

Number of lumbar spines with disc degeneration in two segments

Segments	n	No expected from the null hypothesis	χ^2 ($\chi^2_{0.05} = 3.84$)
L_{1-2} and L_{2-3}	10	3.0	28.0
L_{2-3} and L_{3-4}	10	4.2	12.5
L_{3-4} and L_{4-5}	13	9.5	1.3
L_{4-5} and L_5-S_1	26	16.7	21.2
L_{3-4} and L_5-S_1	15	8.9	10.0

Number of lumbar spines with marginal osteophytes in two segments

Segments	n	No expected from the null hypothesis	χ^2 ($\chi^2_{0.05} = 3.84$)
L_{1-2} and L_{2-3}	10	2.4	26.2
L_{2-3} and L_{3-4}	11	4.6	13.4
L_{3-4} and L_{4-5}	11	4.0	20.0
L_{4-5} and L_5-S_1	8	3.6	7.0

Number of lumbar spines with osteoarthritis in two segments

Segments	n	No expected from the null hypothesis	χ^2 ($\chi^2_{0.05} = 3.84$)
L_{1-2} and L_{2-3}	7	3.2	6.27
L_{2-3} and L_{3-4}	9	3.7	6.23
L_{3-4} and L_{4-5}	13	4.6	16.0
L_{4-5} and L_5-S_1	12	5.0	17.6

n = number of spines with disc degeneration marginal osteophytes or osteoarthritis

The significant intercurrence of osteoarthritis in the L_{4-5} segment and disc degeneration in the L_{3-4} segment (9 intercurrences versus 6.4 expected $\chi^2_{0.05} = 4.16$) cannot be thus explained For (i) osteoarthritis and disc degeneration in the L_{4-5} segment and (ii) disc degeneration in L_{3-4} and L_{4-5} segments were not correlated (Tables 18, 19)

this is reflected by the fact that restorative processes in the form of remodelling of the subchondral bone plate and osteophyte formation adjacent to the capsular attachments begin to appear around the age of 45 (Figs 16, 17)

In about 5 per cent of all the lumbar synovial joints examined there was, regardless of level, a marked difference between the superior and inferior facets of the same joint in the degree of chondral and subchondral osteoarthritic changes (Figs 18 19, 20) Approximately 10 per cent of the joints exhibited similar differences with respect to osteophyte formation in the capsular attachements (Fig 6) Corresponding dissimilarities between the degree of osteoarthritic changes in ipsiarticular joint components were reported by Guntz (1934) in an unspecified proportion of cases Ingelmark (1956 1959) encountered such discrepancies between the facets of approximately 5 per cent of the lumbar synovial joints in a large series of mediaeval skeletons And the same thing in principle was reported by Heine (1926) in knee joints of *autopsy cases with microscopic osteoarthritic changes None of the latter* authors attempted to explain this phenomenon Yet it seems reasonable to assume that these differences reflect the correspondence between the two facets of a synovial joint and the ball and socket of an extremital joint with their somewhat different load distributions This might cause the osteoarthritic changes in the two facets to lose synchronism in their development, at least in a proportion of the lumbar synovial joints Ossification disturbances during the growth of one of the facets might also account for this phenomenon

Osteoarthritic changes confined to particular synovial joints were not seen in the present series of lumbar spines This suggests that local causes acting on isolated synovial joints cannot be a common cause of lumbar osteoarthritis

Osteoarthritic changes in the lumbar synovial joints exhibited a distinct tendency to be associated with particular segments of the lumbar spine (Table 6, Figs 28—32) In the present series of lumbar spines it was thus quite a common observation that the articular cartilages in the L_{4-5} and L_5—S_1 segments exhibited necrosis and substance losses without those in the L_{1-2} and L_{2-3} segments doing so The same applied to such advanced changes in the subchondral bone as extensive sclerosis of the cancellous bone and abundant connective tissue in the subchondral marrow spaces The capsular attachments showed a higher degree of changes in the L_{4-5} segment than in the segments higher up (Fig 32) This observation agrees with what previous workers have noted regarding osteoarthritic changes in the lumbar synovial joints (Guntz, 1934, Putti and Logròscino 1937 Ingelmark 1956 1959)

Putti and Logròscino (1937) ascribed these intersegmental differences to asymmetries of the synovial joints in the lower lumbar segments The corresponding differences in the present series of lumbar spines are not susceptible of such an explanation For perusal of the frontal and lateral X-ray films of spines exhibiting such differences yielded no evidence of such asymmetries It shold be pointed out however, that the presence of synovial joint asymmetry in the lumbar spine cannot be based on X ray examinations alone for the configuration of these joints is such that their joint space readily can be distorted (Reichmann, 1963) In the present investigation this potential source of error was to some extent compensated by the fact that none of the spines showed the combination commonly associated with asymmetry of hypoplasia with malformation of the joint facets on one side compared with those on the opposite side (Putti 1927 Putti and Logroscino 1937 Brocher 1950) But this is not to say that it may not be correct in a particular case of marked joint asymmetry to hold it partly responsible for any osteoarthritis that may be present (cf Horwitz and Smith 1940) Joint asymmetry eems to have contributed little to the development of osteoarthritis in the lumbar synovial joints in large roentgenological series (Brailsford 1929, Soutworth and Bersack 1950) The results of the present investigation seem to bear this out, as does the fact that the frequency of osteoarthritis in the L_{4-5} and L_5—S_1 segments far exceeded the approximately 10 per cent of lumbar spines which according to osteometric investigations (Badgley 1941 Jonck 1961) could have been affected with primary synovial joint asymmetry Moreover such asymmetry seems to be a functional adaption to mechanical stresses to which the joints are exposed (Farkas 1941, Ingelmark 1943) rather than an anomaly that constitutes a locus minoris resistentiae in the lumbar spine

The gradual increase in the average degree of osteoarthritic changes in the synovial joints from the L_{1-2} segment through the L_{4-5} segment followed by a distinct tendency to decrease in the L_5—S_1 segment, suggests that these intersegmental differences reflect anatomical and functional associations between the separate lumbar segments For among other things the anatomical relations in the lumbar spine are such that the synovial joints in the L_{4-5} segment as a rule constitute that pair of joints which support the vertebra at the vertex of the lumbar lordosis (Duhs 1950 Sullivan and Miles 1959) It has been demonstrated that the force of gravity is capable of displacing ventrad those vertebrae below the vertex of the lumbar lordosis (deCuveland and Feser 1958) It is believed that this ventrally directed force is withstood at least partly, by the synovial joints in the L_{4-5} and L_5—S_1 segments Consequently the anatomical relations in the lumbar spine expose the synovial

joints in these segments to increased stress more often than the synovial joints in the three segments above them. Functionally the lumbar spine is characterized by increasing mobility of the vertebrae in relation to the one above from segment L_{1-2} through segment L_{4-5} and then somewhat less mobility of the L_5—S_1 segment (Bakke 1931, Dittmar, 1931 Allbrook 1957) In principle the same mobility pattern was displayed by the lumbar spine preparations in the present investigation Thus the functional relations in the lumbar spine also favour the synovial joints in the upper segments over those in the lower segments from the point of view of mechanical stresses

Osteoarthritis of the lumbar synovial joints was here considered present only when the articular cartilage exhibited both necrosis and substance losses at the same time as the subchondral bone and capsular attachments displayed more or less extensive changes (Figs 6, 17 20) This delimitation of the microscopically observed osteoarthritic changes was adopted because it would provide some idea of the presence of grossly manifest osteoarthritis of the lumbar synovial joints (Fig 33) in a comparable series of lumbar spines Osteoarthritis was encountered already in the age group 26—45 years (Table 7) as previous workers also have done (Guntz 1934, Putti and Logròscino 1937) Notably however, neither of the latter authors specified either the number of segments affected or their site

Consequently the observation made in the present investigation to the effect that osteoarthritis tended to appear initially in the synovial joints in the two upper segments of the lumbar spine (Table 8) cannot be compared with the results of previous studies In a series of skeletons of unspecified age distribution Shore (1935) found the highest incidence of osteoarthritis in the upper segments of the lumbar spine The observation made in the present investigation concerning the level of osteoarthritis in young subjects suggests that Shore s series included a fairly high proportion of young skeletons The anatomical variations described by Davis (1955) in the articular processes forming the so called thoracolumbar mortice joint might be predisposing to early osteoarthritis in some cases According to Davis, a mortice joint — where the inferior articular process cluthes around the superior articular process dorsally — may give rise to a locally increased mechanical strain on the synovial joints in this segment

After age 45 osteoarthritis was exceedingly common in the present series of lumbar spines (Tables 9, 10) Thus at least one of the synovial joints exhibited osteoarthritis in approximately 90 per cent of the lumbar spines over age 45 The corresponding frequencies reported by Guntz (1934) and Putti and Logròscino (1937) were of the order of 50 to 60 per cent The comparatively high frequency observed in the present investigation

is probably due to the fact that it represents microscopically grave osteoarthritis while those of the aforementioned workers represent grossly grave osteoarthritis In the present investigation the intrasegmental frequencies of osteoarthritis were about 60 per cent As a comparison may be mentioned that osteoarthritis manifested by necrosis and substance losses in the articular cartilage combined with subchondral remodelling and connective tissue proliferation has a frequency of 50 to 60 per cent in the knee and hip joints in large autopsy series around age 50 (Heine 1926)

Osteoarthritis is seen isolated in either of the two upper segments of the lumbar spine before age 45 as often as it is seen in the three lower segments simultaneously after age 45 (Tables 7 10) It may be of interest to compare the frequency of this phenomenon 38 per cent with the frequency of 30 per cent Kellgren and Lawrence (1958) reported for osteoarthritis in the lumbar spine found at X-ray examination of 368 subjects between 55 and 64 years of age Considering that these workers recorded roentgenologically demonstrable osteoarthritis osteoarthritis localized to one of the three lower segments of the lumbar spine should have had fairly good chances of remaining undetected owing to the difficulty of visualizing the synovial joints in all segments simultaneously without overlapping When allowance is made for this fact, the frequency of osteoarthritis found in the present investigation would seem to fall within the range of variation of the frequency of roentgenologically demonstrable osteoarthritis of the lumbar synovial joints

The comparison made between the vertebral body joints and the synovial joints in the present series of lumbar spines demonstrates that disc degeneration dominates the morphological changes in the 20—45 years age group (Table 15) At higher ages both osteoarthritis and marginal osteophytes are as common as disc degeneration This agrees with the conclusion that can be drawn by collating previous morphological investigations on the lumbar intervertebral discs (Schmorl 1931 Hirsch and Schajowicz 1952 etc) and on the lumbar synovial joints (Guntz 1934) Intrasegmentally disc degeneration occurred as an isolated phenomenon unaccompanied by either marginal osteophytes or osteoarthritis only in the 20—45 years age group (Table 14) whilst it invariably was associated with either or both the latter conditions above age 45 Similar observations are probably responsible for the current view that osteoarthritis of the lumbar synovial joints in most cases is secondary to disc degeneration (Schmorl 1932 Gantenberg 1930 Hildebrandt 1933 Harris and Macnab 1954) Yet in the present investigation it was a fact that intrasegmentally osteoarthritis occurred unaccompanied by either disc degeneration or marginal osteophytes just as often as isolated

disc degeneration (Table 14), and such isolated osteoarthritis was seen both before and after age 45

A greater than random intercurrence of osteoarthritis and disc degeneration was seen solely in the L_{2-3} and L_5—S_1 segments (Table 18) Because disc degeration has a much earlier onset than osteoarthritis in the L_5—S_1 segment, this intercurrence could here be accounted for by a tendency of disc degeneration to predispose to osteoarthritis If so this would primarily be due to the anatomical relations in the L_5—S_1 segment where the intervertebral disc differs in shape from the other lumbar discs and the joint facets are comparatively more frontally inclined (Junghanns 1933) For if the intervertebral disc is degenerated in this segment, these anatomical relations would cause its synovial joints to be exposed to greater stress than the synovial joints in the other lumbar segments But if the length of time during which disc degeneration exposes the synovial joints to increased functional demands was the sole factor determining whether osteoarthritis would be secondary to disc degeneration, the association between osteoarthritis and disc degeneration should have been positive in the L_{4-5} segment too For the disc in the latter segment exhibited early degeneration as often as the L_5—S_1 disc (Table 15) Actually, however, there was no positive association between osteoarthritis and disc degeneration in the L_{4-5} segment (Table 18)

The greater than random intercurrence of osteoarthritis and disc degeneration in the L_{2-3} segment is not susceptible to a similar explanation for the onset of osteoarthritis took place as early as disc degeneration in this segment (Table 15)

Furthermore, osteoarthritis in the L_{4-5} segment was positively correlated to disc degeneration *in the* L_{3-4} *segment* It should be kept in mind however that when a large number of correlation coefficients are calculated some of them may happen to become numerically positive although the positiveness has no biologically significant background Moreover this writer is convinced that our knowledge of the anatomical and functional relationships of the lumbar spine is so superficial that attempts to interprete associations between different segments would run grave risks of leading to unjustified simplifications Accordingly suffice it to state here that osteoarthritis in the L_{4-5} segment exhibited a positive correlation to disc degeneration in the L_{3-4} segment but this statement makes no pretensions to explain whether or how the two processes are related causally Therefore apart from the L_5—S_1 segment, disc degeneration seems to be neither the sole nor the dominant factor predisposing to the onset and development of osteoarthritis of the lumbar synovial joints

In the present investigation marginal osteophytes on the vertebral bodies seemed to be a condition essentially induced by disc degeneration inter-

acting with ageing (Tables 14 15 16) which is in good agreement with opinions expressed by previous authors (Schmorl 1931 Hildebrandt 1933 Severin 1943) Intrasegmentally moreover there was a greater than random intercurrence of marginal osteophytes and osteoarthritis (Table 17) Similarly in the series of mediaeval skeletons studied by Ingelmark (1956 1959) *there was also a positive correlation between changes on the vertebral* bodies and changes in the synovial joints This might equally well be due to interdependence of marginal osteophytes and osteoarthritis or to both these conditions having a common predisposing factor In the latter case disc degeneration might be considered in the first place However the present investigation no more than previous morphological studies justifies any attempts to interprete such complex fuctional interactions in *the lumbar spine*

CHAPTER 8

Summary

The relevant literature is surveyed. It appears that comparatively little is known about the micromorphology of the lumbar synovial joints in osteoarthritis. Nor do we fully understand the age, sex and intraspinal distribution of lumbar osteoarthritis or its association with other lumbar abnormalities. Hence the present investigation was designed.

This investigation was carried out on a serie of 104 lumbar spines from autopsy cases of both sexes — 18 below and 86 over 20 years of age. The specimens were examined grossly and at X ray. The synovial joints were also examined in the light microscope after sectioning and staining, any morphological changes encountered being graded according to a coding system. Gross disc changes in nucleus pulposus and annulus fibrosus and marginal osteophytes on the vertebral bodies were similarly graded. All the observations were subsequentely subjected to statistical analysis.

The results revealed that all morphological changes in the synovial joints were compatible with the known picture of osteoarthritis in the extremital joints. Thus the lumbar synovial joints as well exhibited a mixture of degenerative and restorative processes, cartilage necrosis and defects in the subchondral bone plate with remodelling of the plate and osteophyte formation in the capsular attachments constituted the most conspicuous and advanced varieties of these processes.

The frequency and degree of osteoarthritic changes in the lumbar synovial joints increased with age equally in both sexes. Before age 45 only minor chondral changes such as cell proliferation, intercellular substance fibrillation and hypertrophy of the calcified zone were the common features in the morphological picture. After that age more advanced chondral changes such as necrosis and substance losses as well as subchondral manifestations like sclerosis, cystic formations with connective tissue proliferation and osteophytes became rather common phenomena. The mean frequency per lumbar spine of joint facets with such extensive chondral and subchondral changes after age 45 amounted to 34.7 ± 8.2 per cent and 13.4 ± 4.4 per cent respectively.

Occasionally the inferior and superior facets of the same synovial joint

exhibited marked differences in the degree of osteoarthritic changes regardless of level in the lumbar spine But within age groups there were no systematic differences between facets Both chondral and subchondral osteoarthritic changes exhibited intersegmental differences in degree — the lower segments of the lumbar spine more often were affected with necrosis and substance losses of the cartilage as well as extensive sub chondral sclerosis with connective tissue proliferation and osteophytes than the two upper segments

Manifest osteoarthritis of the synovial joints was considered present in any segment where at least one joint facet exhibited extensive chondral changes coexistent with conspicuous subchondral changes With this delimitation of the microscopically observed osteoarthritic changes lumbar synovial osteoarthritis was seen in the age group 26—45 years with a segmental frequency of at most about 15 per cent This initial incidence of osteoarthritis tended to occur in the two upper lumbar segments After age 45 about 30 per cent of the examined spines exhibited osteoarthritis in these segments, while in the lower lumbar segments this was the case in about 60 per cent For about 50 per cent of the examined lumbar spines above age 45 osteoarthritis occured in three or more segments simultaneously

Intrasegmentally regardless of age osteoarthritis occasionally occured unaccompanied by either disc degeneration or marginal vertebral osteo phytes Disc degeneration considered as gross changes of nucleus pulposus and annulus fibrosus was seen as the sole pathological change in a lumbar segment only in the 20—45 years age group Up to age 45 disc degenera tion dominated the segmental frequency of morphological abnormalities Thus in the L_{4-5} and L_5—S_1 segments about 35 per cent of the examined spines exhibited disc degeneration while only a few cases showed synovial osteoarthritis and/or marginal vertebral osteophytes After 45 years of age both synovial osteoarthritis and marginal vertebral osteophytes were as common as disc degeneration with segmental frequencies of at most about 60 per cent

While positive intrasegmental correlations occured between synovial osteoarthritis and marginal vertebral osteophytes in all segments of the lumbar spine this was the case for synovial osteoarthritis and disc degeneration only in the L_{2-3} and L_5—S_1 segments

The present investigation shows that one must take into account the lumbar synovial joints in any discussion on morphological basis of low back pain especially after age 45 For the past two or three decades there has been a tendency to concentrate upon the role of the morphology of disc degeneration and marginal osteophytes in studies of the aetiology of lumbar pain with and without radiation This is understandable in view

of the relative ease of X-ray detection of disc and marginal osteophyte changes but it has obscured the importance of the synovial joints In the light of the present investigation it is evident that more emphasis should be placed on the radiologic diagnosis of osteoarthritic changes in the lumbar synovial joints Moreover attempts should be made to define specific clinical entities that can be attributed to osteoarthritic changes in the lumbar synovial joints

Acknowledgements

I am happy to take this opportunity of expressing my deepest gratitude to Professor Bo E Ingelmark M D for giving me guidance support and laboratory facilities in the Department of Anatomy, without which this work would have been impossible He unstintingly offered his vast experience in joint morphology and followed the investigation with the greatest interest

I am also thankful for the privelege of working in the Orthopaedic Department under Professor Carl Hirsch, M D where the pathophysiology of lumbar syndromes has long been a subject of major interest I am grateful for critical discussions and encouragement

I am also indebted to Associate Professor L Zettergren M D, for his help and constructive criticism

This investigation was supported by grants from the Swedish Medical Research Council

Gothenburg August 1964

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TABLE

APPENDIX

TABLE 20

Mean segmental scores and confidence limits for osteoarthritic changes of lumbar spines within age group (cf Figs 21–25)

A.a Cell pattern

Segments	N	M	$\Sigma(X-\bar{X})^2$	$\pm t\ S_{\bar{X}}$	Max	Min	N	M	$\Sigma(X-\bar{X})^2$	$\pm t\ S_{\bar{X}}$	Max	Min
	Age 20–25 years						Age 46–55 years					
L_{1-2}	7	1 71	11 43	±1 28	4	0	17	3 41	39 50	±0 81	6	0
L_{2-3}	9	1 89	24 89	±1 36	4	0	17	3 88	51 86	±0.30	5	0
L_{3-4}	9	2 00	32 00	±1 54	4	0	17	4 24	25 10	±0 65	6	2
L_{4-5}	9	2 22	27 5	±1 43	4	0	17	4.29	61 50	±1 09	8	0
L_5-S_1	8	2.00	24 00	±1 55	4	0	16	4 13	59 5	±1 06	8	1
	Age 26–35 years						Age 56–65 years					
L_{1-2}	13	2.23	11 00	±1 92	6	0	13	2.62	27 10	±0 91	4	0
L_{2-3}	15	1.35	53 20	±1 60	4	0	13	3 46	29 20	±0 94	6	0
L_{3-4}	15	2.80	44 40	±0 97	5	0	13	3 92	40 90	±1 16	8	0
L_{4-5}	14	3 14	12 32	±0 58	4	2	11	4 18	19 60	±0 94	8	2
L_5-S_1	14	2 71	36 85	±0 97	4	0	11	3 82	33 60	±1 23	6	1
	Age 36–45 years						Age > 65 years					
L_{1-2}	14	2 71	36 85	±0 97	4	0	9	4 78	59 6	±2 11	8	0
L_{2-3}	14	3 21	28 36	±0 85	6	0	7	5 71	19 40	±1 44	8	4
L_{3-4}	12	2 83	27 61	±1 07	4	0	9	5 89	20 90	±1.25	8	4
L_{4-5}	15	2 73	36 90	±0 91	4	0	8	5 56	14 00	±1 19	6	4
L_5-S_1	14	2.86	29 70	±0 87	4	0	9	5.33	40 00	±1 72	8	2

Maximum segmental score = 8 (cf p 30)

Table 20 (Cont)

A b Intercellular substance

Segments	N	M	$\Sigma(X-\bar{X})^2$	$\pm t\ S_{\bar{X}}$	Max	Min	N	M	$\Sigma(X-\bar{X})^2$	$\pm t\ S_{\bar{X}}$	Max	Min
	Age 20–25 years						Age 46–55 years					
L_{1-2}	7	2.00	18.00	±1.60	4	0	17	3.88	13.76	±0.48	6	2
L_{2-3}	9	2.11	21.9	±1.27	4	0	17	4.41	18.10	±0.55	8	4
L_{3-4}	9	2.56	45.6	±1.84	4	0	17	4.65	41.90	±0.83	8	4
L_{4-5}	9	2.89	16.90	±1.12	4	0	17	4.12	35.60	±0.78	8	2
L_5-S_1	8	3.25	57.50	±2.40	4	0	16	4.06	64.90	±1.11	8	1
	Age 26–35 years						Age 56–65 years					
L_{1-2}	13	3.92	30.90	±0.97	6	2	13	3.69	22.77	±0.83	6	2
L_{2-3}	15	3.47	21.7	±0.69	5	0	13	4.31	22.77	±0.83	6	2
L_{3-4}	15	3.20	30.6	±0.82	5	0	13	4.54	41.20	±1.12	8	2
L_{4-5}	14	3.43	19.4	±0.71	4	0	11	5.27	42.20	±1.38	8	2
L_5-S_1	14	3.57	11.43	±0.55	5	2	11	4.18	57.60	±1.61	8	1
	Age 36–45 years						Age > 65 years					
L_{1-2}	14	2.57	37.43	±0.98	4	0	9	4.56	33.9	±1.58	8	2
L_{2-3}	14	3.50	25.50	±0.81	5	1	7	5.43	15.70	±1.50	8	4
L_{3-4}	12	3.25	18.25	±0.82	4	0	9	6.56	22.2	±1.28	8	4
L_{4-5}	15	3.53	9.75	±0.46	4	2	8	7.00	10.00	±1.00	8	5
L_5-S_1	14	3.43	11.40	±0.54	4	2	9	5.56	38.20	±1.60	8	2

B Calcified layer

Segments	N	M	$\Sigma(X-\bar{X})^2$	$\pm t\ S_{\bar{X}}$	Max	Min.	N	M	$\Sigma(X-\bar{X})^2$	$\pm t\ S_{\bar{X}}$	Max	Min
	Age 20–25 years						Age 46–55 years					
L_{1-2}	7	0	0		0	0	17	2.24	53.10	±0.94	4	0
L_{2-3}	9	0	0		0	0	17	2.88	89.80	±1.22	8	0
L_{3-4}	9	0	0		0	0	17	2.35	35.90	±0.77	6	0
L_{4-5}	9	0.22	0.99	±0.27	2	0	17	1.82	34.50	±0.76	4	0
L_5-S_1	8	0.80	14.00	±1.19	4	0	16	2.50	58.00	±1.05	6	0
	Age 26–35 years						Age 56–65 years					
L_{1-2}	13	0.85	11.70	±0.60	2	0	13	2.77	60.30	±1.36	8	0
L_{2-3}	15	0.80	30.80	±0.82	4	0	13	3.23	52.30	±1.26	8	0
L_{3-4}	15	1.00	53.00	±1.08	6	0	13	3.54	17.30	±0.73	4	0
L_{4-5}	14	0.79	11.36	±0.54	3	0	11	3.45	16.73	±0.87	4	0
L_5-S_1	14	2.00	38.00	±0.99	4	0	11	3.09	24.90	±1.06	4	0
	Age 36–45 years						Age > 65 years					
L_{1-2}	15	1.27	44.90	±0.99	4	0	9	3.22	45.20	±1.06	6	1
L_{2-3}	15	1.27	36.90	±0.90	4	0	7	4.00	56.00	±2.83	8	0
L_{3-4}	13	1.85	32.70	±1.00	4	0	9	4.00	40.00	±1.72	8	0
L_{4-5}	16	1.69	33.40	±0.79	4	0	8	4.50	22.00	±1.49	8	-
L_5-S_1	15	1.33	45.30	±1.00	4	0	9	3.56	45.90	±1.85		

Table 20 (Cont.)

C. Subchondral bone

Segments	N	M	$\Sigma(x-\bar{x})^2$	$\pm t\ s_{\bar{x}}$	Max	Min	N	M	$\Sigma(x-\bar{x})^2$	$\pm t\ s_{\bar{x}}$	Max	Min
	Age 20—25 years						Age 46—55 years					
L_{1-2}	7	0	0		0	0	17	2.18	67.42	±1.05	5	0
L_{2-3}	9	0.22	0.996	±0.27	0	0	17	2.24	47.05	±0.88	4	0
L_{3-4}	9	0	0		0	0	17	2.53	34.24	±0.75	4	0
L_{4-5}	9	0	0		0	0	17	2.76	31.06	±0.72	4	0
L_5-S_1	8	0	0		0	0	16	2.81	36.44	±0.83	4	0
	Age 26—35 years						Age 56—65 years					
L_{1-2}	13	0.77	20.31	±0.78	4	0	13	1.77	29.86	±0.95	5	0
L_{2-3}	15	0.67	16.35	±0.60	4	0	13	2.46	41.23	±1.12	4	0
L_{3-4}	15	0.33	7.33	±0.40	4	0	13	2.77	36.31	±1.06	4	0
L_{4-5}	14	1.14	31.71	±0.90	4	0	11	4.09	16.91	±0.87	6	2
L_5-S_1	14	1.14	31.71	±0.90	4	0	11	3.55	16.73	±0.87	5	1
	Age 36—45 years						Age > 65 years					
L_{1-2}	14	0.44	8.32	±0.46	2	0	10	2.40	28.02	±1.00	4	0
L_{2-3}	14	1.79	36.37	±0.97	4	0	8	3.31	23.32	±1.53	4	1
L_{3-4}	12	1.92	28.92	±1.03	4	0	10	4.50	40.50	±1.52	8	2
L_{4-5}	15	1.13	29.63	±0.81	4	0	9	5.11	18.89	±1.18	8	4
L_5-S_1	14	1.43	27.43	±0.84	4	0	10	4.00	32.00	±1.36	8	2

D. Capsular attachment

Segments	N	M	$\Sigma(x-\bar{x})^2$	$\pm t\ s_{\bar{x}}$	Max	Min	N	M	$\Sigma(x-\bar{x})^2$	$\pm t\ s_{\bar{x}}$	Max	Min
	Age 20—25 years						Age 46—55 years					
L_{1-2}	8	0			0	0	17	0.24	3.06	±0.23	1	0
L_{2-3}	9	0			0	0	17	0.76	29.06	±0.69	3	0
L_{3-4}	9	0			0	0	17	1.12	47.76	±0.89	6	0
L_{4-4}	9	0			0	0	17	1.88	33.76	±0.75	4	0
L_5-S_1	8	0			0	0	16	1.33	23.75	±0.67	4	0
	Age 26—35 years						Age 56—65 years					
L_{1-2}	13	0			0	0	13	1.00	60.00	±1.35	8	0
L_{2-3}	15	0.27	8.93	±0.44	1	0	13	1.15	19.70	±0.78	4	0
L_{3-4}	15	1.07	4.93	±0.33	2	0	13	1.62	55.08	±1.30	6	0
L_{4-5}	14	1.00	38.00	±0.99	5	0	11	2.45	46.73	±1.45	6	0
L_5-S_1	14	0.29	4.86	±0.35	2	0	11	1.18	19.63	±0.94	4	0
	Age 36—45 years						Age > 65 years					
L_{1-2}	14	0	0		0	0	9	1.56	19.51	±1.21	4	0
L_{2-3}	14	0.50	9.50	±0.49	2	0	7	2.14	28.84	±2.03	6	0
L_{3-4}	12	0.92	26.92	±0.99	4	0	9	3.44	22.22	±1.28	6	0
L_{4-5}	15	0.73	26.93	±0.77	4	0	8	4.50	30.10	±1.74	6	0
L_5-S_1	14	0.21	4.36	±0.27	2	0	8	1.88	40.88	±2.02	6	0

TABLE 21

Frequency of joint facets with osteoarthritic changes of grades 0, 1 or 2 (cf. p. 27) in separate lumbar spine segments

A a Cell pattern

Age	20–25			26–35			36–45			46–55			56–65			> 65 years		
Grade	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Segments																		
L_{1-2}	14	12	0	21	25	2	12	42	0	9	52	3	10	34	0	3	14	14
L_{2-3}	14	14	0	32	34	0	11	49	2	8	54	7	6	35	5	0	12	14
L_{3-4}	12	20	0	12	40	1	11	36	0	1	59	9	3	39	3	1	13	20
L_{4-5}	14	20	0	6	42	0	20	45	0	2	47	13	2	38	4	0	20	12
L_5-S_1	12	16	0	11	38	0	12	44	0	2	38	13	0	30	6	0	16	16

A b Intercellular substance

Age	20–25			26–35			36–45			46–55			56–65			> 65 years		
Grade	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Segments																		
L_{1-2}	12	14	0	3	38	4	12	39	0	0	61	3	0	40	4	0	23	11
L_{2-3}	11	19	0	5	50	1	9	44	3	0	56	8	0	37	9	0	14	12
L_{3-4}	7	23	0	8	44	1	6	37	0	0	48	17	0	37	11	0	9	25
L_{4-5}	6	26	0	2	50	0	3	53	0	0	54	8	0	29	15	0	8	24
L_5-S_1	4	26	0	0	49	1	0	52	0	0	46	12	0	26	10	0	10	18

B Calcified layer

Age	20–25			26–35			36–45			46–55			56–65			> 65 years		
Grade	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Segments																		
L_{1-2}	26	0	0	37	9	0	34	29	0	28	34	2	17	55	6	5	25	2
L_{2-3}	30	0	0	44	12	0	41	19	0	24	39	6	14	40	14	6	12	8
L_{3-4}	30	0	0	40	13	0	23	24	0	27	33	3	8	66	8	3	20	8
L_{4-5}	32	2	0	39	11	0	34	28	0	31	31	0	8	54	8	2	24	8
L_5-S_1	24	4	0	22	27	0	38	22	0	21	37	6	12	44	10	8	16	8

TABLE 21 (cont)

C. Subchondral bone

Age	20–25			26–35			36–45			46–55			56–65			> 65 years		
Grade	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Segments																		
L_{1-2}	26	0	0	40	10	0	46	8	0	30	32	3	22	21	1	13	18	1
L_{2-3}	29	2	0	44	10	0	29	29	0	30	38	0	16	28	2	3	23	0
L_{3-4}	32	0	0	45	5	0	24	23	0	23	39	2	12	36	0	0	27	7
L_{4-5}	36	0	0	32	16	0	43	19	0	18	41	3	4	35	5	0	22	10
L_5-S_1	30	0	0	32	14	1	32	24	0	14	37	4	0	31	3	2	24	6

D Capsular attachment

Age	20–25			26–35			36–45			46–55			56–65			> 65 years		
Grade	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Segments																		
L_{1-2}	26	0	0	41	0	0	51	1	0	56	4	0	34	4	5	19	12	1
L_{2-3}	30	0	0	48	3	1	49	9	0	51	9	2	30	15	0	13	15	2
L_{3-4}	30	0	0	46	3	0	36	11	0	50	10	4	30	16	3	8	19	5
L_{4-5}	32	0	0	34	13	1	48	14	0	30	24	3	24	13	7	5	16	10
L_5-S_1	26	0	0	42	4	0	51	3	0	39	11	3	26	9	2	15	11	2

TABLE 22

Differences of segmental scores (cf p 30) for osteoarthritic changes between age groups t values in paranthesis ware not significant at a 5 per cent level (For number of examined spines see Table 20)

Age groups compared	26–35/20–25 Diff	SD	t	36–45/20–25 Diff	SD	t	36–45/26–35 Diff	SD	t	46–55/20–25 Diff	SD	t	46–55/26–35 Diff	SD	t
							A a Cell pattern								
L_{1-2}	0.52	1.12	(0.95)	1.00	1.59	(1.36)	0.48	1.38	(0.84)	1.70	1.52	2.15	0.70	1.62	(1.2)
L_{2-3}	−0.29	1.88	(0.37)	1.32	1.59	(1.94)	1.61	1.74	2.49	2.28	2.14	3.01	0.67	1.66	(1.2)
L_{3-4}	0.80	1.78	(1.07)	0.83	1.77	(1.06)	0.03	1.70	(0.05)	2.24	1.54	3.28	1.44	1.52	2.68
L_{4-5}	0.92	1.32	(1.64)	0.51	1.70	(0.71)	−0.41	1.35	(0.80)	2.07	1.15	4.36	1.15	1.60	(1.99)
L_5-S_1	0.71	1.74	(0.92)	0.86	1.64	(1.18)	0.15	1.60	(0.26)	2.13	1.13	4.35	1.42	1.85	2.09
							A b Intercellular substance								
L_{1-2}	1.92	1.64	2.49	0.57	1.71	(0.72)	−1.35	1.66	(2.11)	1.88	1.20	2.66	−0.04	1.26	(0.86)
L_{2-3}	1.36	1.41	4.01	0.94	1.81	(1.19)	0.03	1.11	(0.08)	2.30	1.29	4.32	0.94	1.15	2.30
L_{3-4}	0.64	1.86	(0.81)	1.39	1.50	2.17	0.05	1.40	(0.09)	2.09	1.91	2.65	1.45	1.55	2.64
L_{4-5}	0.18	1.32	(0.37)	0.64	1.11	(1.50)	0.10	1.03	(0.27)	1.23	1.48	(2.01)	0.69	1.38	(1.39)
L_5-S_1	*0.32*	*1.86*	*(0.38)*	*0.18*	*1.87*	*(0.22)*	*−0.14*	*0.94*	*(0.13)*	*0.81*	*2.45*	*(0.76)*	*0.49*	*1.65*	*(0.83)*
							B Calcified layer								
L_{1-2}	0.85	0.80	2.25	1.27	1.50	(1.85)	0.42	1.47	(0.75)	2.24	1.56	3.14	1.39	1.51	2.49
L_{2-3}	0.80	1.18	(1.60)	1.27	1.30	2.31	0.47	1.56	(0.80)	2.88	1.93	3.63	2.08	2.00	2.86
L_{3-4}	1.00	1.55	(1.53)	1.85	1.28	3.29	0.85	1.82	(1.23)	2.35	1.22	4.60	1.35	1.82	2.10
L_{4-5}	0.57	0.76	(1.75)	1.69	1.20	3.37	0.90	1.26	(1.95)	1.60	1.21	3.20	1.03	1.26	2.27
L_5-S_1	1.50	1.61	(2.10)	0.83	1.65	(1.15)	−0.67	1.76	(1.03)	2.00	1.81	2.55	0.50	1.85	(0.74)

Note Table 3 and 4 show this information in a simplefied form (cf p 63)

Table 22 (Cont)

Age groups compared	46–55/36–45 Diff	S D	t	56–65/20–25 Diff	S D	t	56–65/26–35 Diff	S D	t	56–65/36–45 Diff	S D	t	56–65/46–55 Diff	S D	t
A a Cell pattern															
L_{1-2}	0 70	1 62	(1 20)	0 91	1 46	(1 45)	0 39	1 26	(0 79)	–0 09	1 60	(0 15)	–0 79	1 55	(1 36)
L_{2-3}	0 57	1 66	(0 95)	1 57	1 64	(1 32)	1 86	1 78	2 76	0 25	1 66	(0 40)	–0 42	1 70	(0 70)
L_{3-4}	1 41	1 39	2 74	1 92	1 91	2 30	1 12	2 07	(1 19)	1 09	1 73	(1 56)	–0 32	1 55	(0 54)
L_{4-5}	1 56	1 81	2 43	1 96	1 62	2 74	1 04	1 18	2 19	1 32	1 53	2 14	–0 11	1 77	(0 16)
L_5-S_1	1 27	1 79	(1 94)	1 82	1 84	2 13	1 11	1 75	(1 58)	0 96	1 66	(1 43)	–0 31	1 00	(0 77)
A b Intercellular substance															
L_{1-2}	1 31	1 33	2 74	1 69	1 49	2 43	–0 23	1 49	(0 33)	1 12	1 55	(1 98)	–0 19	1 14	(0 45)
L_{2-3}	0 91	1 23	2 06	2 20	1 50	3 39	0 84	1 31	(1 70)	0 81	1 39	(1 60)	–0 10	1 20	(0 23)
L_{3-4}	1 40	1 49	2 49	1 98	2 08	2 28	1 34	1 66	2 13	1 29	1 61	2 11	–0 11	1 73	(0 19)
L_{4-5}	0 59	1 23	(1 35)	2 48	1 81	3 03	1 84	1 66	(2 04)	1 74	1 47	2 99	1 15	1 73	(1 71)
L_5-S_1	0 63	1 93	(0 89)	0 93	2 60	(0 78)	0 61	1 42	(0 84)	0 75	1 73	(1 07)	0 12	2 21	(0 14)
B Calcified layer															
L_{1-2}	0 97	1 81	(1 51)	2 77	1 83	3 14	1 92	1 73	2 83	1 50	2 01	(1 97)	0 53	2 01	(0 68)
L_{2-3}	1 61	2 05	2 20	3 23	1 62	4 62	2 43	1 79	3 60	1 96	1 85	2 79	0 35	2 25	(0 43)
L_{3-4}	0 50	1 57	(0 86)	3 54	0 93	8 78	2 54	1 64	3 99	1 69	1 44	3 09	1 19	1 38	2 34
L_{4-5}	0 13	1 48	(0 81)	3 23	0 99	7 36	2 66	1 63	4 04	1 76	1 43	3 13	1 63	1 40	3 00
L_5-S_1	1 17	1 87	(1 74)	2 59	1 51	3 73	1 09	1 65	(1 64)	1 76	1 29	3 42	0 59	1 82	(0 81)

Age groups compared	> 65/20–25 Diff	S D	t	> 65/26–35 Diff	S D	t	> 65/36–45 Diff	S D	t	> 65/46–55 Diff	S D	t	> 65/56–65 Diff	S D	t
A a Cell pattern															
L_{1-2}	3 09	2 25	2 73	2 55	1 88	3 14	2 07	2 14	2 24	1 37	2 02	(1 96)	2 16	2 08	2 40
L_{2-3}	3 82	1 78	4 20	4 11	1 91	4 73	2 50	1 58	3 25	1 83	1 80	2 26	2 25	1 64	2 92
L_{3-4}	3 89	1 82	4 50	3 09	1 70	4 36	3 06	1 60	6 50	1 65	1 39	2 89	1 97	1 76	2 59
L_{4-5}	3 34	1 66	4 01	2 42	1 35	4 11	3 03	1 56	3 94	1 27	1 81	(1 64)	1 38	1 41	(2 11)
L_5-S_1	3 33	2 07	3 33	2 62	1 91	3 20	2 47	1 82	3 30	1 20	2 03	(1 44)	1 51	2 02	(1 66)
A b Intercellular substance															
L_{1-2}	2 56	1 75	2 64	0 64	1 80	(0 82)	1 99	1 84	2 53	0 68	1 41	(1 16)	0 87	1 68	(1 19)
L_{2-3}	3 32	1 44	4 08	1 96	1 37	3 12	1 93	1 47	2 84	1 02	1 24	(1 83)	1 12	1 46	(1 63)
L_{3-4}	4 00	2 07	4 16	3 36	1 55	5 14	3 31	1 46	5 23	1 91	1 63	2 85	2 02	1 78	2 62
L_{4-5}	4 11	1 34	6 29	3 57	1 21	6 64	3 47	0 97	8 19	2 88	1 41	4 44	1 73	1 94	(1 91)
L_5-S_1	2 31	2 53	(1 89)	[illegible]	1 54	3 03	2 13	1 54	3 24	1 50	2 04	(1 76)	1 38	2 37	(1 33)
B Calcified layer															
L_{1-2}	3 22	1 80	3 55	2 37	1 69	3 25	1 55	2 02	2 28	0 98	2 02	(1 18)	0 65	2 30	(0 65)
L_{2-3}	4 00	2 00	3 87	3 20	2 06	3 35	2 73	2 15	2 78	1 12	2 57	(0 99)	0 77	2 45	(0 67)
L_{3-4}	4 00	1 58	5 36	3 00	2 06	3 42	2 15	1 91	2 60	1 65	1 78	2 26	0 46	1 69	(0 65)
L_{4-5}	4 28	1 24	7 07	3 71	[illegible]	6 48	2 81	1 59	2 77	2 68	1 57	4 02	1 15	1 51	(1 62)
L_5-S_1	3 66	2 00	3 15	1 56	2 00	(1 83)	2 23	2 04	2 59	1 06	2 13	(1 18)	0 47	1 97	(0 54)

Table 22. (Cont)

Age groups compared	26–35/20–25 Diff	S D	t	36–45/20–25 Diff	S D	t	36–45/26–35 Diff	S D	t	46–55/20–25 Diff	S D	t	46–55/26–35 Diff	S D	t
C. Subchondral bone															
L_{1-2}	0.77	1.07	(1.53)	0.44	0.66	(1.19)	0.33	1.07	(0.81)	2.18	1.75	2.77	1.41	1.77	2.16
L_{2-3}	0.45	0.89	(1.20)	1.57	1.33	(0.77)	1.12	1.40	2.16	2.02	1.41	3.76	1.57	1.45	3.05
L_{3-4}	0.33	0.57	(1.36)	1.92	1.24	3.59	1.59	1.20	3.40	2.53	1.20	5.14	2.20	1.18	5.17
L_{4-5}	1.14	1.23	2.18	1.13	1.16	2.31	−0.01	1.51	(0.18)	2.76	1.14	5.91	1.62	1.47	3.05
L_5–S_1	1.14	1.26	(2.04)	1.43	1.17	2.25	0.29	1.37	(0.58)	2.81	1.29	4.61	1.67	1.56	2.92
D. Capsular attachment															
L_{1-2}	±0			±0			±0			0.24	0.36	(1.55)	0.24	0.33	(0.85)
L_{2-3}	0.27	0.64	(1.07)	0.5	0.67	(0.55)	0.23	0.83	(0.73)	0.76	1.10	(1.66)	0.49	1.13	(1.23)
L_{3-4}	0.27	0.47	(1.37)	0.92	1.19	(1.75)	0.65	1.13	(1.26)	1.12	1.41	(1.94)	0.85	1.33	(1.81)
L_{4-5}	1.0	1.35	(1.42)	0.73	1.06	(1.64)	−0.27	1.55	(0.48)	1.88	1.19	3.84	0.88	1.57	(1.[illegible]5)
L_5–S_1	0.29	0.49	(0.44)	0.21	0.47	(1.01)	−0.08	0.62	(0.34)	1.13	1.04	2.5	0.84	0.97	2.35

Age groups compared	46–55/36–45 Diff	S D	t	56–65/20–25 Diff	S D	t	56–65/26–35 Diff	S D	t	56–65/36–45 Diff	S D	t	56–65/46–55 Diff	S D	t
C. Subchondral bone															
L_{1-2}	1.74	1.62	2.91	1.77	1.29	2.96	1.79	1.49	3.18	1.33	1.24	2.79	−0.41	1.86	(0.60)
L_{2-3}	0.45	1.70	(0.73)	2.24	1.45	3.56	1.79	1.49	3.17	0.67	1.77	(0.98)	0.22	1.77	3.37
L_{3-4}	0.61	1.53	(1.06)	2.77	1.35	4.74	2.44	1.30	4.98	0.85	1.60	(1.28)	0.24	1.59	(0.41)
L_{4-5}	1.63	1.46	3.15	4.09	0.97	8.27	2.95	1.46	5.02	2.96	1.39	5.36	1.33	1.36	2.63
L_5–S_1	1.38	1.51	2.50	3.55	0.96	7.02	2.41	1.46	4.10	2.12	1.39	3.79	0.74	1.46	(1.30)
D. Capsular attachment															
L_{1-2}	0.24	0.33	(2.0)	1.18	1.07	2.37	1.00	1.58	(1.61)	1.00	1.55	(1.68)	0.76	1.51	(1.37)
L_{2-3}	0.26	1.15	(0.81)	1.15	0.99	2.65	0.88	1.05	2.22	0.65	1.08	(1.56)	0.39	1.32	(0.80)
L_{3-4}	0.20	1.54	(0.34)	1.62	1.66	2.37	1.35	1.52	2.34	0.70	1.89	(1.15)	0.50	1.92	(0.70)
L_{4-5}	1.15	1.42	2.28	2.45	1.61	3.38	1.45	1.92	(1.87)	1.72	1.75	3.12	0.57	1.76	(0.84)
L_5–S_1	0.92	1.41	(1.78)	1.18	1.07	2.38	0.89	1.03	2.09	0.94	1.02	2.41	0.05	1.37	(0.11)

Age groups compared	> 65/20–25 Diff	S D	t	> 65/26–35 Diff	S D	t	> 65/36–45 Diff	S D	t	> 65/46–55 Diff	S D	t	> 65/56–65 Diff	S D	t
C. Subchondral bone															
L_{1-2}	2.40	1.37	3.55	1.63	1.52	2.56	1.96	1.28	3.72	0.22	1.95	(0.28)	0.63	1.66	(0.85)
L_{2-3}	3.16	1.27	5.12	2.71	1.37	3.90	1.59	1.73	(2.08)	1.14	1.75	(1.[illegible]6)	0.92	1.84	(1.05)
L_{3-4}	4.50	1.54	6.21	4.17	1.44	7.09	2.58	1.86	3.41	1.97	1.70	2.92	1.73	1.91	2.15
L_{4-5}	5.11	1.09	7.43	3.97	1.55	[illegible].99	3.98	1.49	6.37	2.35	1.44	4.00	1.02	1.45	3.89
L_5–S_1	4.00	1.41	5.96	2.86	1.70	3.60	2.57	1.64	3.60	1.19	1.69	(2.02)	0.45	1.92	(0.60)
D. Capsular attachment															
L_{1-2}	1.56	1.14	2.82	1.56	0.98	3.59	1.56	0.96	3.74	1.32	0.97	3.42	0.56	1.97	(0.66)
L_{2-3}	2.14	1.44	2.95	1.87	1.37	2.97	1.64	1.42	2.50	1.38	1.62	(1.89)	0.99	1.68	(1.27)
L_{3-4}	3.44	1.18	6.19	3.17	1.11	6.78	2.52	1.61	3.48	2.32	1.71	3.25	1.82	1.97	2.13
L_{4-5}	4.50	1.42	6.57	3.50	1.84	4.20	3.77	1.66	4.52	2.62	1.67	3.67	2.05	2.13	(2.0[illegible]
L_5–S_1	1.89	1.71	2.20	1.59	1.51	2.37	1.67	1.50	2.50	0.75	1.71	(1.02)	0.70	1.89	(0[illegible]

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Printed in Sweden
ORSTADIUS BOKTRYCKERI AKTIEBOLAG
GÖTEBORG 1964

ACTA ORTHOPAEDICA SCANDINAVICA
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From the Orthopaedic Hospital, Copenhagen, Denmark. Dept. 1 (Head: Professor A. Fertelsen), Dept. 2 (Head: E. Hjalmar Larsen), Dept. 3 (Head: A. Monberg).

PRINTED IN DENMARK
ALD. PEDERSENS BOGTRYKKERI
COPENHAGEN

Contents

1 Review of the Literature

A *Introduction*

It is generally known that the longitudinal growth of the diaphyses of long bones takes place only by apposition from the epiphysial plates

The histology and cytology of the epiphysial plate has been rather thoroughly studied On the other hand the detailed mechanisms which condition normal symmetrical longitudinal growth and the pathogenetic factors which may stimulate or retard longitudinal growth are practically unknown However a number of clinical and experimental findings indicate that changes in the blood supply of the epiphysial plates play an important role in growth intensity

The blood supply of the long bones has been investigated int al by *Weinmann & Sicher* (1947) *Trueta & Harrison* (1953) *Trueta* (1958) *Trueta & Cavadias* (1955) *Lewis* (1956) *Trueta & Morgan* (1960) *Trueta & Little* (1960) *Trueta & Amato* (1960) and *Trueta & Trias* (1961) The epiphyses receive their blood supply from epiphysial vessels The metaphysis is supplied primarily by the nutrient arteries but during the growing phase also to an increasing extent by metaphysial vessels Between epiphysial and metaphysial vessels there are ample extraosseous anastomoses along the periphery of the epiphysial plate but endosteal anastomoses are not present between these two vascular systems until growth has been completed

It has been known for a long time that in a large number of diseases abnormal stimulation of the longitudinal growth of long bones may occur

This has been observed *e g* in congenital anomalies vascular diseases systemic diseases and following infections traumas and sympathetic denervation

In arteriovenous anastomoses (*Broca* 1856 *Horton* 1932 *Belrand & Trillat* 1948 *Bertelsen & Dohn* 1953) and in "systemic haemangiomas" (*Servelle* 1948 *Harris & McDonald* 1936) considerable overgrowth of the affected limb may be observed Severe overgrowth has been reported in Recklinghausen s neurofibromatosis

Cases of overgrowth have also been reported to be due to osteomyelitis, chronic suppurative infections of soft tissues and joints (*v. Lan... et al.* 1869, *Trueta* 1953) and to fractures as well as other skeletal ... (*Ollier* 1867, *Emneus* 1957, *Levander* 1929, *Aitken* 1940, *Blom... & Lindstrom* 1943, *Hedberg* 1944–45, *Barfod & Christensen* 1959, ...*ildhammer* 1963).

Following sympathectomy overgrowth has occasionally been observed in the denervated area (*Bidder* 1874, *Harris & McDonald* 1936).

These findings have stimulated a large number of experimental and clinical attempts at reproducing the growth stimulating mechanisms with the purpose of working out a clinically applicable method for growth stimulation. *Ollier* (1867–73) appears to have been the first to perform growth stimulation experiments on a larger scale. From a number of more or less specified experiments he concluded that all agents which irritate the periosteum and bone, such as incisions, excisions, dilacerations, cauterizations, perforations of the medullary cavity and implantation of foreign material resulted in intensified longitudinal growth.

Ollier's observations inspired to a large number of studies of a similar nature.

Below follows a review of the various methods used in the attempt to stimulate the longitudinal growth of the long bones experimentally or [illegible]

... *al Stripping*

... *al experiments*

... [illegible] iosteal stripping on infant rabbits *Wu & Millner* (1937) ... [illegible] 1947) and *Langenskiold* (1957) found a growth stimulation ... [illegible] mm, while *Sousa Pereira* (1937) was unable to demonstrate any effect. The most extensive and most thoroughly analysed experimental material in this respect is *Brodin's* (1955). Following periosteal stripping proximally on the tibiae of 44 infant rabbits he found during the first post operative week stimulation of both epiphysial plates on the tibia but at the end of one week the growth intensity from the proximal epiphysial zone fell to below normal and remained so until the completion of growth, while distally the intensity continued to be a little above normal. The end result thus was only a slight increase in the growth rate.

2 *Clinical experience*

Bertrand & Trillat (1948) *Zanoli* (1949) and *Taillard* (1959) performed periosteal stripping on children with shortening of a lower limb All found mild stimulation of growth or mild retardation of the progression of anisomelia However the results cannot be assessed owing to the inaccuracy of the measurement and the inaccuracy in evaluating the spontaneous course

C *Implantation of Foreign Material*

In animal experiments *Meisenbach* (1910) *Königswieser* (1925 1926) *Pilzen* (1928) *Bohlmann* (1929) *Kischikawa* (1936) *Wu & Miltner* (1937) *Bertrand & Trillat* (1948) *Chapchal & Zeldenrust* (1948) and Herndorn & Spencer (1953) implanted a large number of different organic and inorganic substances in the vicinity of the epiphysial plates This resulted in a maximum stimulation of a few millimetres and frequently in inhibition of growth *Langenskiöld* (1957) and *Haas* (1958) found no growth stimulation following injection of pituitary growth hormone into the medullary cavity

Wilson & Percy (1956) found an unreliable and varying growth stimulation following implantation of dissimilar metals into the metaphyses of animals When applied clinically this method gave no effect

von Langenbeck (1869) reported growth stimulation following implantation of an ivory screw into the femur of a dog

Chapchal & Zeldenrust (1948) found on the average a slight and extremely varied stimulation by ivory implants in rabbits

In 10 patients with anisomelia *Pease* (1952) inserted screws of various metals or of ivory into the metaphyses at the knee The results are reported only for 7 of the patients Assuming that if untreated the shortening would have progressed in proportion to time at an unchanged rate *Pease* calculated that by the ivory screws he had obtained a stimulation of from 0 8–1 1 cm and by metal screws 0 0–2 2 cm The methods of measurement or the technique of the procedure are not specified The inaccuracy of the measurement cannot be assessed and the follow up period was in some cases not longer than 6 months *Pease* recommended insertion of ivory screws for clinical use but in 1956 he had abandoned this technique and recommended instead the introduction of dissimilar metal compounds

Blount & Zeier (1952) as well as *Kramer* (1955) claimed to have observed positive results with Pease s method of inserting ivory screws

On the other hand *Montgomery & Ingram* (1956) found growth stimulation to be less common and did not feel that the clinical use of Pease s method was justified In 12 out of 16 patients with progressive shortening *Tupman* (1960) found a decreased rate of progression following implantation of ivory screws or ox bone into the metaphyses at the knee but no real decrease in the anisomelia

D *Occlusion of the Medullary Cavity*

Ferguson (1933) made drill holes into the metaphyses and cut the bone marrow at the knee in 16 children with anisomelia He reported the results only for 4 who showed a stimulation of 1 6–3 2 mm in a follow up period of 2–5 months It is not stated how this was demonstrated

Ferguson s method was tested experimentally on rabbits by *Compere & Adams* (1937) and by *Wu & Miltner* (1937) without demonstrable effect and on puppies by *Hutchison & Burdeaux* (1954) who found an average growth stimulation of 1 mm in half of 10 treated animals and none in the others

This method has been employed clinically in a modified form by *Carpenter & Dalton* (1956) In addition to making drill holes in the metaphyses and curetting the bone marrow they packed the defect with ivory chips In 26 out of 28 children they obtained an average stimulation of 0 7 cm

On the basis of clinical experience of growth stimulation following fractures and osteomyelitis *Trueta* (1953) believes that the stimulation appears chiefly when the lesions are localized to the diaphyses and that it is active only while the medullary cavities are occluded

E *Occlusion of the Nutrient Arteries*

Haas (1917) found no alteration in longitudinal growth after severing the nutrient arteries in dogs and cats

Trueta (1953) found no growth stimulation after severing the nutrient arteries of rabbits while blocking of their lumina with wax or periosteal stripping around the nutrient foramen resulted in a growth stimulation which is not further specified

Brookes (1957) closing the nutrient arteries of 1 day old rabbits found no alteration in growth until towards its completion which was premature

F *Arteriovenous Anastomoses*

Bertrand & Trillat (1948) suggested trying surgical formation of arteriovenous anastomoses in the treatment of anisomelia.

In 5 out of 8 patients in whom arteriovenous anastomosis had been established on the lower limbs *Janes & Jennings* (1961) found an average decrease of the existing anisomelia of 2.7 cm after an average follow-up period of 4.4 years. In the other 3 patients the shortening progressed. All the patients developed considerable cardiac dilatation which however subsided when the anastomosis was closed. A number of the patients developed varicose veins.

Hiertonn (1961) set up an anastomosis between the femoral artery and vein proximally on the femur of 5 children suffering from the sequaelae of poliomyelitis and progressive anisomelia. After the anastomosis had been open for periods ranging from 5.3 to 7.5 years the anisomelia had decreased by 3.0–6.5 cm. All the patients developed varicose veins and 3 ulcer of the leg which healed after normal circulation had been re-established. There was no instance of demonstrable cardiac complications or permanent late sequelae. Arteriography after the procedure showed extremely ample vascularization around the epiphysial zones at the knee.

G *Venous Stasis*

The earliest reports on a growth stimulating effect of venous stasis were *Helferich's* (1887), *Schuller's* (1889) and *Bier's* (1905).

In rabbit experiments *Bergmann* (1931) using venous stasis and *Kishikawa* (1936) using external stasis or ligation of the femoral vein found mild growth stimulation in some of the animals.

Ligating the femoral vein, the great saphenous or the popliteal vein on 7 puppies *Servelle* (1948) found a growth stimulation of 2.6–7.6 per cent. However, he does not describe his measuring method.

Hutchison & Burdeaux (1954) applying stasis to the forelegs of 11 dogs found no alteration in growth intensity. Using the same procedure on the hind legs of 6 dogs they found an average growth increment of 1.45 per cent both on the femora and tibiae although the stasis had been applied immediately above the knee.

On the other hand *Wu & Miltner* (1937) ligating the femoral artery on 11 rabbits and *Dickinson* (1953) ligating the popliteal and iliac veins in a very carefully studied material of 8 dogs found no demonstrable growth stimulation during the treatment.

II. *Sympathetic Denervation*

1. *Animal experiments*

Bidder (1874) observed considerable hypertrophy of a rabbit ear following cervical sympathectomy.

Kishikawa (1936) obtained mild growth stimulation following lumbar sympathectomy on puppies.

Gullickson, Kubicek & Kottke (1951) applied electrical stimulation to the sympathetic trunk of 10 puppies through 23–70 days. Measurements on post mortem specimens thereafter showed an average shortening of 2.8 mm on the stimulated side. In 6 puppies treated by lumbar sympathectomy they found invariably a lengthening on the denervated side of 2.7–14.0 mm, average 6.5 mm. In a normal control series the maximum value was 1 mm and the average difference in length 0.2 mm.

Cannon et al. (1929), *Simon* (1930), *Bacq* (1930), *Bergmann* (1931), *Bisgard* (1933), and *Harris & McDonald* (1936) found no definite growth stimulation following sympathectomy on animals.

Goetz, du Toit & Swart (1955) found a mild lengthening of the paw but no alteration in the length of the femur or tibia following lumbar sympathectomy on 2 rabbits.

Ring (1961) performing total lumbar sympathectomy on 11 puppies found mild lengthening in only 3 and no influence upon growth in the others.

Troupp (1961) found inhibition of longitudinal growth in rabbits in which ischaemia had been induced on a hind limb. Lumbar sympathectomy was unable to compensate for this inhibition of growth.

2. *Clinical experience*

Harris & McDonald (1936) had followed 46 polio patients after lumbar sympathectomy. In 21 an existing anisomelia decreased—in 2 cases by more than 2.5 cm, in 4 by more than 1.9 cm, and in the remaining 15 by less than 1.3 cm. The results are based on the clinical measurement of the shortening. In 1945 *Harris & McDonald* in a discussion reported that they had performed more than 400 lumbar sympathectomies on polio patients. They found that further progression was arrested and that frequently the anisomelia decreased, in one case from 4.25 cm to 0.6 cm.

In one patient with progressive congenital anisomelia *Bertrand & Trillat* (1948) found a reduction of the shortening of 1.5 cm 2 years after lumbar sympathectomy.

Barr et al (1950) had followed 23 polio patients after lumbar sympathectomy These patients showed an average reduction of the shortening of 0 3 cm as compared with an average increase of 1 8 cm in a control group The age at onset of the disease in the control group not being stated it cannot be seen whether the two groups are comparable When *considering the inaccuracy of the measurement only 3 patients* obtained a definite reduction of the shortening

Fahey (1936) found no alteration of longitudinal growth after lumbar sympathectomy on 2 children with Hirschsprung s disease

Steward (1937) following 6 children with cerebral palsy after lumbar sympathectomy found in 6 years a growth increase of half an inch (1 2 cm) in only 2 children

I *Effect of Short wave Diathermy*

The influence of short wave diathermy upon the longitudinal growth has been studied by *Buchtala* (1948 1949) *Wise et al* (1949) *De Forest et al* (1953) and *Vaughen & Bender* (1959) In no case was there a growth stimulating effect but on high doses they found extensive destructions of bone epiphysial plate and joint cartilage

J *Effect of Heat*

This was studied by *Ring & Lee* (1958) In 4 children suffering from the sequelae of poliomyelitis they maintained a temperature of 40 C around the epiphysial zones at the knee No influence upon longitudinal growth was demonstrated

Upon electrical heating of the epiphysial regions of animals *Richards & Stofer* (1959) found a growth increment of 2–6 per cent

K *Effect of X radiation*

X radiation has been suggested for stimulating growth Its effect has been studied by *Brooks & Hillstrom* (1933) *Bisgard & Hunt* (1936) and *Barr et al* (1943) None of these authors found a growth stimulating effect but on the contrary growth retardation on high dosage

L *Discussion*

This review does not include investigations comprising at the same time several different procedures aiming at growth stimulation as in such cases it is impossible to evaluate the effect of the individual components

Periosteal stripping has not given definite growth stimulation in animal experiments The clinical results cannot be assessed with certainty

The reported results of implanting foreign material have varied However most investigators have found a slight effect which cannot be evaluated in relation to the spontaneous course

Occlusion of the medullary cavity has not afforded a definite effect in animal experiments but in clinical use it appears to have resulted in some slight stimulation of growth

Most authors have found no or only negligible stimulatory effect of venous stasis

Surgical establishment of arteriovenous anastomoses entailed striking stimulation of growth in both of the reports published so far but gave rise to severe cardiac and vascular complications

The effect of sympathetic denervation has been extremely varied according to the different authors both in experimental and in clinical use Some have found a striking effect others a milder effect and others again no definite effect.

Long-continued application of heat to the epiphyseal zones may possibly result in slight growth stimulation while X-radiation short wave diathermy and occlusion of the nutrient arteries do not appear to be of definite effect

Thus most of the methods studied have afforded little or no definite effect and have been used only sporadically for clinical cases

Surgical establishment of arteriovenous anastomoses appears to involve such severe complications as to prohibit its clinical use

Implantation of ivory screws into the metaphyses as introduced by *Pease* (1952) still seems to be in use but on the basis of the literature it seems impossible to evaluate the effect of this procedure with accuracy

Lumbar sympathectomy is reported by some authors having experience of large series to exert a striking growth stimulating effect Others have found the effect to be nil or so slight that the obtained growth stimulation was of no clinical value

Accordingly we felt prompted to study the growth stimulating effect obtained by Pease's procedure and by lumbar sympathectomy on a series of patients from the Orthopaedic Hospital Copenhagen

2 Present Investigations

Our patient material for evaluating the growth stimulating effect of ivory implants is larger than any published before On the other hand the material for assessing the effect of lumbar sympathectomy is small compared with a number of previous series However both studies are based upon radiological measurement and both series are of a size which permits statistical evaluation of the results

A *Material*

The Pease procedure was done on 26 patients 12 boys who had the operation in the age range 5 years 7 months to 13 years average 9 years 10 months and 14 girls in the age range 4 years 11 months to 9 years 10 months average 7 years 6 months The operation was carried out on 23 femora and 21 tibiae a total of 44 bones

The anisomelia which indicated growth stimulation had been caused by the sequelae of acute anterior poliomyelitis in 22 patients and by congenital diseases in 4

Lumbar sympathectomy was done on 11 patients In 6 it was impossible to assess the effect either in the femur or in the tibia because of operations upon the contralateral bone during the follow up period Thus the effect could be assessed in the case of 16 bones All these patients were suffering from the sequelae of poliomyelitis which had occurred 3–11 years average 6 years 1 month before the procedure Four patients were boys who had the operation at ages ranging from 6 years 7 months to 11 years 11 months average 9 years 6 months and 7 were girls operated upon during the age range 8 years 11 months to 12 years 6 months average 11 years 0 month

In both series we included only patients on whom the procedure was performed a minimum of 3 years after the onset of the disease and a maximum of 3 years before the completion of growth We excluded any patients who had had the Pease operation as well as lumbar sympathectomy and those subjected to other operations on the treated or the untreated contralateral bone during the follow up period

B *Methods*

The *Pease operation* was carried out according to the technique described by *Pease* (1952) After making drill holes 1 or 2 ivory screws were inserted into the metaphysis distally on the femur or proximally on the tibia The screws were applied transversely through the metaphysis in its entire width and as close as possible to the epiphyseal cartilage plate without injuring it

In the *lumbar sympathectomy* 2 or 3 ganglia were removed This was confirmed by histological study

On all patients spot orthoradiographic measurement was performed prior to the procedure Patients having the Pease procedure were followed for a minimum of 3 years and patients having lumbar sympathectomy for a minimum of 2 years by regular spot radiographic measurements

Calculation of Results

On the basis of the spot-orthoradiographic measurements growth curves were plotted in all cases for the femora and tibiae as a function of age By means of these curves the difference between the femora and tibiae in each individual patient was measured at the time of the operation and postoperatively at 12 month intervals

All operations were done on patients having progressive anisomelia Thus a stimulation of growth may have occurred even though decreasing anisomelia could not be demonstrated after the operation

Apparently there are marked individual variations in the spontaneous course of anisomelia following poliomyelitis (*Green* 1949 *Ring* 1958 *Ratliff* 1959) and there seem to have been no previous studies on the course of anisomelia in congenital diseases It was impossible therefore to carry out accurate calculations of how far the anisomelia would have progressed if the operations had not been done

It appears to be generally agreed however that the anisomelia following poliomyelitis does not start until a year or two after the onset of the disease and then rapidly progresses during the subsequent 3–4 years From 4 5 years after the onset and until the completion of growth however the anisomelia seldom seems to progress as rapidly as previously

In order to assess the effect of the operations in relation to the spontaneous course the results obtained by both methods were calculated in two way

A. As the actual equalization obtained within the individual postoperative years by deducting the measured anisomelia 12, 24 and (after the Pease intervention) also 36 months after the operation from the anisomelia found one year previously. Thus negative results indicate continued progression of the anisomelia.

B. The expected anisomelia at the times of follow up was calculated on the basis of the anisomelia at the time of operation and the duration of the disease, the progression rate being presumed to be equal during the postoperative and preoperative period. From this computed anisomelia we deducted the measured anisomelia. The results are given as progression within the 1st, 2nd or 3rd postoperative year. Positive statements thus mean that the progression rate has been less than that presumed in relation to the duration of the disease.

The methods of calculation are illustrated graphically in Fig. 1. Values a_1, a_2, a_3 indicate the actual equalization obtained during the 1st, 2nd and 3rd postoperative year; b_1, b_2 and b_3 indicate the difference between the calculated and measured progression of anisomelia within the 1st, 2nd and 3rd postoperative year.

C. *Results*

1. *Pease Procedure*

The results are given in Tables 1 and 2. It will be seen that during the first postoperative year the anisomelia progressed by an average of 0.77 mm, in the second year by 2.11 mm, and in the third year by 2.02 mm.

This means that—assuming that the anisomelia would have increased in proportion to the duration of the disease (Fig. 3)—there had been an average stimulation during the first year of 1.57 mm, in the second year 0.61 mm, and in the third year 0.57 mm.

Thus, after the operation the shortening showed an average increase but not as rapid as in the preoperative period, especially not during the first preoperative year. The spontaneous course being unknown, it is impossible to decide whether this course represents real stimulation or a spontaneous course.

The difference between the progression of anisomelia during the first and the subsequent two postoperative years may be indicated by the formula (cf. Fig. 1)

$$2a_1 - (a_2 + a_3)$$

This value was calculated for all bones in the Pease series.

TABLES 1, 2, 4 and 5
Distribution of the results of growth stimulating operations
(For explanation see text and Fig. 1)

	Equalization obtained mm		9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	Total No. of obs.	Equalization mean value ($\bar{x}$) mm	Equalization standard deviation (s_x) mm
			−																			+			
Table 1	Real	a_f				3	2	1	7	1	7	8	3	5	5								44	−0.77	±2.5
[illegible]	equalization	a			1	1	5	4	5	7	8	7	2	1				1					44	−2.11	±2.5
operation	(No. of obs.)	a_t	1			3	1	6	6	5	10	3	1	2									44	−2.02	±2.3
Table 2	Computed	b_f						1	2	2	3	8	3	10	5	6	2	1		1			44	+1.57	±2.5
[illegible]	equalization	b						2		7	4	3	14	10	2	1					1		44	+0.61	±2.2
operation	(No. of obs.)	b_t					1		2	2	4	11	8	7	3	2	1						44	+0.57	±1.9
Table 4	Real																								
Lumbar	equalization	a_t			1	2		2	2	1	2	4	1			1							16	−2.00	±2.9
sympathectomy	(No. of obs.)	a				2		1	1	1	5	5				1							16	−1.38	±2.5
	Computed																								
Table 5	equalization																								
Lumbar	(No. of obs.)	b_t						1	1		3	1	2	3	3			2					16	+1.11	±2.8
sympathectomy		b						1		1	3	2		4	3	2						1	16	+1.69	±3.2

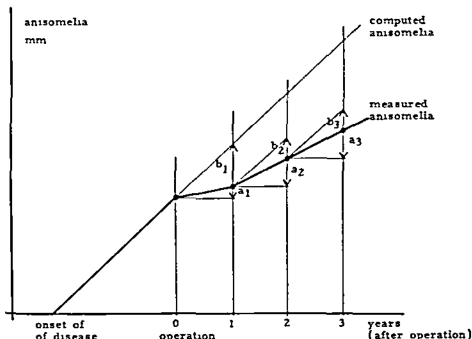


Fig 1

Graphic representation of the methods used for calculating the results a_1 a_2 a_3 and b_1 b_2 b_3

TABLE 3

Difference between progression of anisomelia during the 1st and during the 2nd + 3rd years after the Pease operation

(For explanation see text and Fig 1)

$2a_1 - (a_2 + a_3)$ mm	− 15	12	9	6	3	0	+ 3	6	9	Total	mean value ( ) mm	standard deviation (s_x) mm
No of obs	1	2	3	8	10	9	9	1	1	44	− 2 32	± 5 0

The distribution of the results may be read from Table 3

The standard deviation (s_x) for the results is ± 5 0 mm and the mean value −2 32 mm The mean value differs significantly from 0 ($p<1$ per cent)

In other words the average annual progression of the anisomelia has been 2 32 mm greater during the second and third than during the first postoperative year

It has been demonstrated then that the progression rate was signi

ficantly slower during the first postoperative than the subsequent 2 postoperative years. This course must represent a growth stimulating effect of the operations during the first postoperative year since according to the experience gained so far regarding the spontaneous course of anisomelia following poliomyelitis it is hardly conceivable that a material of the present size would show a temporary average spontaneous reduction in the progression rate.

Of course a spontaneous decrease in the progression rate might be imagined during the first 2 or 3 years after the onset of the disease and during the last 2 or 3 years before the completion of growth, but none of the operations was carried out during these periods. Nor is a temporary spontaneous reduction in the progression rate in the middle of the growing period likely in the 4 cases of congenital diseases.

On the other hand the course during the 2nd and 3rd postoperative years may represent a spontaneous course, the progression of the anisomelia having been almost as rapid as during the preoperative period.

Investigation of the inaccuracy of the measurement in spot orthoradiographic measurement revealed a standard deviation of ± 2.5 mm on the results in measuring the difference between 2 of the bones in the lower limbs (*Nordentoft*, in press). Since the results in the present study are based upon the measurement of the difference between 2 different times, the error might result in a standard deviation of

$$\pm 2.5 + 2.5 = \pm 3.54 \text{ mm}$$

Presuming a normal distribution of the results, maximum variations from the mean value of twice the standard deviation might be expected, *i.e.* about 7 mm, merely as a result of the inaccuracy of measurement. In calculating the results b_2 and b_3 the inaccuracy of the measurement of the difference at the time of operation must also influence the results, which will consequently differ by more than 7 mm from the mean value—merely because of the inaccuracy of measurement.

When this inaccuracy of the measurement is taken into consideration in assessing the individual results, none of the latter can be taken to represent a growth stimulation greater or lesser than the average.

2. Lumbar Sympathectomy

The results were calculated in the same way as after the Pease procedure, but it was impossible to follow the effect in a sufficient number of patients for more than 2 postoperative years.

Tables 4 and 5 give the results. They show that the anisomelia in

creased by an average of 2.00 mm during the first and by 1.38 mm during the second postoperative year. The increment in anisomelia was during the first year an average of 1.19 mm and during the second year an average of 1.69 mm less than would have corresponded to a progression proportional to the duration of the disease. When related to the standard deviation on the results and the inaccuracy of the measurement, the average and individual results do not differ significantly from 0.

The course may easily represent a spontaneous course, and thus the results cannot be taken to stand for a growth stimulating effect.

However, it can also not be excluded on the basis of the results of this study that lumbar sympathectomy may reduce the progression rate of anisomelia following poliomyelitis. However, the present results make it seem unlikely that this intervention might in some cases entail a real reduction of existing anisomelia of several centimetres—as reported by a few authors.

A further analysis of the influence of lumbar sympathectomy upon the longitudinal growth of the lower limbs would seem to be obtainable only by a statistical evaluation of a larger series and pair au pair comparison with a definitely comparable control series.

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When this inaccuracy of the measurement is taken into consideration in assessing the individual results, none of the latter can be taken to represent a growth stimulation greater or lesser than the average.

2. Lumbar Sympathectomy

The results were calculated in the same way as after the Pease procedure, but it was impossible to follow the effect in a sufficient number of patients for more than 2 postoperative years.

Tables 4 and [illegible] the results. They show that the anisomelia in

I Summary

In a study of the effect of inserting ivory screws into the metaphyses of 44 long bones in the lower limbs of 26 patients the authors found a significant average growth stimulation of the magnitude 2 mm during the first postoperative year. On the other hand no growth stimulating effect could be demonstrated during the subsequent 2 years and the growth stimulation was in no case significantly greater than the average effect.

The effect of lumbar sympathectomy was followed on 16 long bones in 11 patients. No definite stimulation of growth was found although it cannot be ruled out that the procedures may have inhibited the development of further anisomelia.

It is concluded that the effect of implanting ivory screws into the long bones of the lower limbs as well as the effect of lumbar sympathectomy upon longitudinal growth is so slight and uncertain that these procedures are not justified in the treatment of anisomelia.

3 Conclusion

It must be justified therefore to conclude that insertion of ivory screws into the metaphyses at the knee entailed a significant growth stimulation of an average magnitude of 2 mm during the first postoperative year No case showed a growth stimulation significantly exceeding the average effect The effect has disappeared completely or very nearly in 1 year

Therefore the effect obtained is so slight that it does not justify a continued clinical application of this procedure

From the present results it must be permitted to conclude that the growth stimulating effect of lumbar sympathectomy is so uncertain that it is not justified to use the method in the treatment of anisomelia This is not saying of course that the procedure cannot be indicated for the treatment of vascular disturbances in poliomyelitis patients

4 Summary

In a study of the effect of inserting ivory screws into the metaphyses of 44 long bones in the lower limbs of 26 patients the authors found a significant average growth stimulation of the magnitude 2 mm during the first postoperative year On the other hand no growth stimulating effect could be demonstrated during the subsequent 2 years and the growth stimulation was in no case significantly greater than the average effect

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PRINTED IN DENMARK
VALD. PEDERSENS BOGTRYKKERI
COPENHAGEN

ACTA ORTHOPAEDICA SCANDINAVICA
Supplementum No 75

Aus der Abteilung fur Funktionelle Anatomie des Gymnastiska Centralinstitutet
(Vorstand Prosektor S Carlsoo)
der Anatomie des Karolinska Institutet (Vorstand Professor T Petren) und
der Orthopadischen Klinik des Karolinska Institutet (Vorstand Professor S Friberg)
Stockholm, Schweden

EINE UNTERSUCHUNG DER FERSENBELASTUNG BEIM GEHEN

EINE METHODE FÜR DIE MESSUNG DER FERSENBELASTUNG IM SCHUH

von

HILDING WETZENSTEIN

Mit einem Appendix über die Konstruktion der Messapparatur von

Arne Söderholm

MUNKSGAARD

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Seite 30

Zeile 3 von unten steht
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Seite 3

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Arne Söderholm

Stockholm 1964

P nted Sweden
NY tryck ab Bottnaryd 1964

Inhaltsverzeichnis

Vorwort

Zur Ausführung der vorliegenden Arbeit wurden mir die Hilfsmittel der Institutionen für Funktionelle Anatomie des Gymnastiska Centralinstitutet der Anatomie und der Orthopädischen Klinik des Karolinska Institutet *grosszügig zur Verfugung gestellt Hierfür und fur das stetige persönliche* Interesse und die Bereitwilligkeit zur Diskussion der Probleme möchte ich Prosektor Sven Carlsöö Professor Sten Friberg und Professor Ture Petren besonders danken

Bei der Planung der Messmethode erwies mir mein Lehrer med dr Åke Jakobsson grosses Interesse und gab mir alle erdenkliche Unterstützung

Durch das Entgegenkommen des Rektors des Gymnastiska Centralinstitutet Gymnastikdirektör Paul Högberg konnten die Studenten jederzeit an den Versuchen teilnehmen Ich bin ihm und allen Studenten sehr zu Dank verpflichtet

Ingenjor Arne Soderholm (SEG Instrument A B Stockholm) konstruierte die Messapparatur *uber deren Funktion er selbst in einem Appendix* berichtet

Eine Waage zur Testung der Messapparatur wurde in Zusammenarbeit mit Instrumentenbauer Harry Hagelin an der Physiologischen Abteilung des Gymnastiska Centralinstitutet konstruiert Die technische Überwachung der elektronischen Ausrüstung lag in den Handen von Ingenjor William Johannsen

Die statistische Bearbeitung des gegebenen Versuchsmateriales erfolgte unter der Leitung von fil kand Avo Raud (Stockholms Universitet) Bei der

Durchfuhrung der statistischen Berechnungen war fil kand Eva Ohlsson (Stockholms Universitet) behilflich

Fur die Herstellung der Abbildungen danke ich Fräulein Karin Lundin

Die Finanzierung der Arbeit geschah mit Beitragen von
Jönköpings Lans Landsting
Karolinska Institutet (Reservationsanslag)
und Statens Konsumentrad

Eine speciell konstruierte Serie von Schuhen wurde von AB PAX Sko industri Örebro zur Verfugung gestellt

Einleitung

Der Kliniker ist im Hinblick auf Deformitaten des Fusses die eine pathologische Belastung verursachen an einem naheren Studium der Fussbelastung interessiert In Fallen mit ausgepragten Supinations oder Pronationsfehlstellungen z B konnen pathologische Belastungsverhaltnisse durch Inspektion des entkleideten Fusses im Stehen und Gehen gedeutet werden Sie konnen auch in sekundaren durch abnormen Druck verursachten Hautverdickungen und Skelettdeformierungen zum Ausdruck kommen In Fallen mit weniger ausgepragten pathologischen Befunden ist die Beurteilung der Fussbelastung unsicher

Einer klinischen Beurteilung der Belastung des Fusses im Schuh begegnen noch grossere Schwierigkeiten Besonderheiten in Verschleiss und Deformierung des Schuhes konnen Fehlstellungen und Fehlbelastungen vermuten lassen Fur eine nahere Untersuchung der Fussbelastung im Schuh bedarf es jedoch spezieller Methoden Es ist offenbar dass Probleme der Fussbelastung nicht isoliert gesehen werden konnen ohne dass die Abhangigkeit der Fussbelastung von der Funktion anderer Teile des Bewegungsapparates erortert wird Die Belastung des Fusses ist vom Zusammenspiel verschiedener Teile des Bewegungsapparates abhangig Funktionelle Störungen in irgend einem dieser Teile und nicht nur solche im Bereich des Fusses konnen auf die Belastung einwirken

Von mehreren Verfassern sind Untersuchungen ausgefuhrt worden um die funktionellen Zusammenhange des Bewegungsapparates unter physiologischen und pathologischen Bedingungen zu studieren Eine Durchsicht der Literatur bestatigt welchen bedeutenden Schwierigkeiten man bei den Versuchen alle erforderlichen Data fur eine Analyse der Bewegungen und des Ruhezustandes einzusammeln begegnet Die zyklographischen Untersuchungen z B von Fischer (1901) und anderen zeigen dies deutlich

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Verschiedene Methoden für Untersuchungen der Belastung des Fusses im Schuh und des unbeschuhten Fusses sind entwickelt worden Ausführliche Zusammenstellungen über diese Methoden findet man im Californischen Rapport der Universitet Berkeley (1947) bei Hohmann (1948), Scherb (1952) und Drillis (1958)

Es war die Absicht mit Hilfe solcher Methoden u a die Biomechanik des Fusses naher zu untersuchen und den Verlauf von pathologischen Zustanden sowie den Effekt von therapeutischen Massnahmen objektiv zu registrieren

Man bediente sich technisch verschiedenartiger Konstruktionen für eine quantitative Registrierung der Reaktionskrafte des Fusses im Schuh und/oder der Unterlage Im Prinzip können Methoden die fur eine Messung der Verteilung der Belastung auf die verschiedenen Stutzpunkte des Fusses abgesehen waren von denen die die Summe der Krafte samtlicher mit der *Unterlage in Beruhrung befindlichen Teile des Fusses registrierten* unterschieden werden

Im ersten Falle bedarf es mehrerer über die Belastungsflache des Fusses verteilter Druckrezeptoren Je grosser deren Anzahl gewahlt wird, desto vollstandiger entsteht das Belastungsbild Die Rezeptoren mussen demnach relativ klein sein

Im anderen Falle wird der Rezeptor so gross gewahlt dass er dem ganzen Fuss Platz gibt

Weitere prinzipielle Unterschiede zwischen den verschiedenen Methoden bestehen in der Wahl der registrierten Kraftkomposanten von vollständigen Messungen aller Komposanten (vertikale horizontale und rotatorische) zu Messungen einzelner von ihnen

Bei Messungen der Belastungsverteilung auf die Stützpunkte des Fusses ist stets nur die vertikale bzw die senkrecht gegen die Belastungsflache des Schuhes gerichtete Kraftkomposante gemessen worden Eine Einbeziehung ubriger Kraftkomposanten hätte im Hinblick auf die Vielzahl und die Kleinheit der Rezeptoren bedeutende technische Schwierigkeiten bereitet

Bei Messungen der summierten Kraft sämtlicher mit der Unterlage in Beruhrung befindlicher Teile des Fusses mit relativ grossen Messplatten bestanden technisch bessere Voraussetzungen fur Messungen mehrerer oder samtlicher Kraftkomposanten

Die meisten publizierten Methoden sind technisch kompliziert und bieten Schwierigkeiten bei der Auswertung der Resultate Näheres über diese Methoden siehe nachstes Kapitel

In der vorliegenden Arbeit berichtet der Verfasser über eine eigene teilweise bereits publizierte Methode (Wetzenstein 1960) die durch ihre relative technische Einfachheit eine Untersuchung grösseren Materiales ermöglicht Der Messbereich dieser Methode ist auf die Ferse begrenzt, und es wird die Lage des Angriffspunktes und die Grösse der senkrecht gegen die Absatzebene des Schuhes gerichteten Kraftresultante gemessen

Es war weiter die Absicht zu untersuchen ob Messungen dieser Art zu *einem näheren Studium der Funktion des Fusses beim Gehen in Schuhen* beitragen konnten

Es wurden auch durchschnittliche Normalwerte fur die 6 Punkte errechnet Aus den bisherigen Berichten geht jedoch nicht hervor mit Hilfe welchen Materiales diese Normalwerte gewonnen wurden und wie gross die Variationen waren Ein statistischer Vergleich von Werten pathologischer Belastung und den genannten Normalwerten ist bisher offenbar nicht publiziert worden

Holden und Muncey (1953) verwendeten ein technisch ahnliches Verfahren wie Schwartz und Heath für Messungen dynamischer Fersenbelastung beim Gehen in Schuhen Eine elektronische Messplatte (double condensor) wurde so in den Schuh gelegt dass sie den Fersenbereich ausfüllte Der druckempfindliche Teil der Messplatte bestand jedoch nur aus einem halbmondformigen Bereich von ½ square inch Sie untersuchten die Einwirkung verschiedener Fussboden auf die Quantitat und den Zeitablauf der Fersenbelastung Sie fanden grosse Variationen zwischen Versuchspersonen jedoch nur geringe von einem Schritt zum anderen derselben Versuchsperson Verschiedenheiten der Fussböden hatten keinen Einfluss auf die Belastungskurven

Bauman und Brand (1963) publizierten eine Methode mit 5 kleinen (1 mm dick 1 cm gross) Messplatten die auf gewahlten Stellen der Fussohle aufgeklebt wurden und offenbar den von Schwartz und Heath angegebenen entsprachen In wie weit sie technisch eine Verbesserung darstellen kann aus der Publikation nicht entnommen werden Mit Hilfe von konventionellen Fussabdrücken wurden die am meisten belasteten Bereiche des zu untersuchenden Fusses lokalisiert und die Messplatten dementsprechend angebracht Bauman und Mitarbeiter (1963) undersuchten in dieser Weise systematisch den Einfluss verschiedener Schuhkonstruktionen auf die Fussbelastung bei Lepra deformitaten

Allgemein kann hier gesagt werden dass Vergleiche von Messungen an gewählten Bereichen der Fussohle zwischen Individuen nur in begrenzten Umfang moglich sind da eine genauere und vergleichbare Orientierung zwischen Messplatten und anatomischen Strukturen kaum erzielt werden kann

Methoden fur Messungen der Belastungs Kräfte zwischen den Stutzpunkten des Fusses in seiner Gesamtheit und der Unterlage

Die chronozyklographischen Studien Fischers gaben theoretisch Möglichkeiten die Belastung des Fusses mit Hilfe der Bewegungsbahnen der Schwerpunkte aller Körpersegmente zu errechnen Weder Fischer noch andere Verfasser die mit dieser Methode arbeiteten haben jedoch solche Berechnungen ausgeführt Sie ist sehr umständlich und es bestehen Schwierig

keiten die Grosse der Masse der einzelnen Korpersegmente und deren Schwerpunkte mit ausreichender Genauigkeit zu bestimmen

Fur Messungen der Krafte zwischen Fuss und Unterlage sind verschiedene Typen von Messplatten erarbeitet worden die für den ganzen Fuss Platz geben und alle Komposanten d h vertikale horizontale und rotatorische Kraft oder je nach Konstruktion einzelne von ihnen registrierten Das für diese Messplatten Gemeinsame liegt darin dass alle belasteten Stutzpunkte des Fusses summiert gemessen werden ohne dass die Verteilung der Belastung angegeben werden könnte Es besteht jedoch die Moglichkeit den Angriffspunkt der Resultante der vertikalen Kraft im Verhältnis zur Belastungsflache des Fusses zu bestimmen

Amar (1916) beschrieb eine mechanisch arbeitende Apparatur die aus zwei nebeneinander liegenden 3 Meter langen Messplatten bestand fur jeden Fuss eine mit welchen vertikale und horizontale Belastung pneumatisch registriert wurde

Basler (1935) und Schenk (1936) untersuchten die beim Gehen nach abwarts wirkende Lotkraft mit einem an einer Saite aufgehangten Brett das in die Gehbahn eingefällt war Die Schwingungszahl der Saite als Mass für die Quantitat der Belastung wurde mit dem gefilmten Bewegungsablauf der unteren Extremitat verglichen

(Basler (1936) konstruierte auch einem Apparat für Messungen der Verteilung der Belastung auf die Stutzpunkte des Fusses mit 10 an Saiten aufgehängten Schienen)

Elftman (1938 1939) publizierte einen Apparat fur Messung der vertikalen und horizontalen Krafte Zwei mechanisch unabhangig voneinander arbeitende Einheiten waren so in einer Messplatte zusammengefügt dass die eine die vertikalen und die andere die horizontalen Krafte registrierte Die Belastung wurde durch Federn mechanisch gemessen Durch Berechnung der Kraftmomente konnte die Lage des Angriffspunktes der vertikalen Kraft auf der Messplatte bestimmt werden Um seine Lage im Verhaltnis zur Belastungsflache des Fusses angeben zu konnen verfertigte Elftman Fussabdrücke auf der Messplatte mit dem fruher von ihm beschriebenen Verfahren mittels Gummimatte (siehe Seite 13) Es bestanden danach Moglichkeiten fur Messungen der Grösse der vertikalen und horizontalen Krafte und der Lage des Angriffspunktes der vertikalen Kraft im Verhältnis zur Belastungsflache des Fusses

Elftman zeigt in einem Diagram die Wanderung des Angriffspunktes der vertikalen Kraft innerhalb eines Fussabdruckes von der Ferse zur grossen Zehe wahrend der Abwickelung einer Fussbelastung Es wird nicht von Ver



Abb. [illegible] zeigt die Reaktionskräfte zwischen Schuh und Unterlage und die Wanderung des R[illegible] der vertikalen Kraft für eine normale Versuchsperson beim Gehen auf [illegible] Ebene mit [illegible] Messplatten registriert (force plate)
(A[illegible] Ca[illegible] University Berkeley Report to national research council fig [illegible])

gleichen zwischen Individuen berichtet Elftman ausserte Since the mode of walking varies widely it can only be investigated by a series of experiments with controlled variation of factors Solche Untersuchungen sind bisher offenbar nicht ausgeführt worden

Im Rahmen eines Forschungsprogrammes an der Californischen Universitat in Berkeley uber den Gang des Menschen wurde diese Art von Messplatten weiterentwickelt (Cunningham 1952) An Stelle von Federn in Spiralform wurden stehende Metallzylinder als Tragpfeiler fur die Messplatte verwendet Die Deformierungen der Pfeiler bei Belastung der Messplatte konnten mit Hilfe von Dehnungsmesstreifen elektronisch registriert werden Alle Komposanten der Kraft liessen sich selektiv messen (vertikale horizontale und rotatorische) Es kamen jedoch gewisse Überlagerungen zwischen den Komposanten vor die bei Berechnung der Resultate durch Einfuhrung eines Kalibrierungsfaktors berucksichtigt wurden Um die Lage der Resultante der vertikalen Kraft auf die Belastungsflache des Fusses beziehen zu konnen verwendete man ahnlich wie Elftman ein Fussabdruckverfahren War die Lage des Fusses auf der Platte bestimmt konnte die Lage des Angriffspunktes innerhalb der Belastungsflache des Fusses angegeben werden Dieses Verfahren bot jedoch gewisse Schwierigkeiten die mitunter dazu fuhrten dass der berechnete Angriffspunkt ausserhalb des Fussabdruckes lag

In den publizierten Diagrammen wurde die Wanderung des Angriffspunktes der vertikalen Kraft uber die Belastungsflache des Schuhes der Quantitat der verschiedenen Kraftkomposanten gegenubergestellt (Abb 1)

Ahnliche Messplatten wurden spater von Harper und Mitarbeiter (1960) und Carlsoo (1962) beschrieben

Eine systematische Untersuchung der Fussbelastung mit Vergleichen zwischen Individuen ist bisher offenbar mit diesen Methoden nicht durchgefuhrt worden

In veterinarmedizinischem Zusammenhang ist von Björck (1958) eine Messplatte zur Untersuchung der Zugkraft des Pferdes entwickelt worden Er montierte Messplatten die die vertikale und horizontale Kraftkomposante registrierten unter den Huf Sie beruhten auf dem Prinzip der Federwaage Die Deformierungen der Feder wurden mittels Dehnungsmesstreifen gemessen Ahnlich den Verhältnissen bei den Californischen Messplatten wurden beide Kraftkomposanten in ein und demselben Federarm aufgefangen Die Federarme waren also in zwei Richtungen biegbar und die Dehnungsmesstreifen dementsprechend aufgeklebt

Fur ein Studium der Fersenbelastung beim Gehen im Schuh erschienen die bisher publizierten Methoden weniger geeignet

KAPITEL III

Die eigene Methode

1 MESSAPPARATUR

Der Verfasser bediente sich einer bereits vorher von ihm publizierten Methode fur Messungen der Fersenbelastung im Schuh (Wetzenstein)

Eine Messplatte war so konstruiert worden dass sie die winkelrecht gegen sie gerichtete Kraft registrierte und eine Berechnung des Angriffspunktes ihrer Resultante ermoglichte Die Belastungsplatte ruhte mit ihrem Zentrum auf einer dreiarmigen steifen Federwaage Die Stutzpunkte der Federwaage bestanden aus Stahlkugeln die sich bei Belastung der Platte auf dem Boden des Instrumentes verschieben liessen (Abb 2) Deformierungen der Federarme wurden mittels Dehnungsmesstreifen gemessen Die Widerstandsanderungen die in den Dehnungsmesstreifen entstanden wurden mit Hilfe geeigneter Bruckenkreise in elektrische Spannungsanderungen umgewandelt Die Speisung dieser Bruckenkreise erfolgte mit Gleichspannung und die Registrierung der Spannungsanderungen mit Spiegelgalvanometern in einem Schreiber (Typ Visicorder Oscillograph)

Die Summe der Deformierungen der 3 Arme der Federwaage entsprach der totalen Belastung Der Grad der Deformierung in den einzelnen Armen der Federwaage ermoglichte eine Berechnung der Lage des Kraftzentrums (=Kraftresultante) auf der Messplatte folgender Formeln gemass (siehe auch Seite 89)

$$z = \frac{k}{E} \ (U_1 + U_2 + U_3)$$

$$y = \frac{\frac{\sqrt{3}}{2}(U_2 - U_3)}{U_1 + U_2 + U_3} \quad L$$

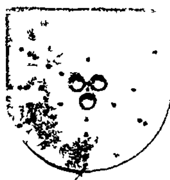
$$x = \frac{U_1 - \frac{1}{2}(U_2 + U_3)}{U_1 + U_2 + U_3} \quad L$$

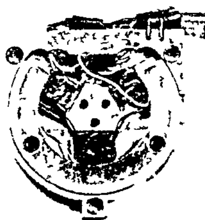
z^* = totale winkelrecht gegen die Platte gerichtete Kraft
k = Kalibrierungsfaktor
E Spannung mit welcher die elekerische Brucke gespeist wurde
U_1 U_2 und U_3 = Ausschlage der Spiegelgalvanometer der drei Arme der Federwaage
y = Abstand des Angriffspunktes der Resultante von der X Axe der Messplatte in mm
x Abstand des Angriffspunktes der Resultante von der y Axe (Queraxe) der Messplatte in mm
L = Konstante

*) In der ersten Publikation der Methode wurden an Stelle von z y und x die Symbole P ρ und α verwendet)



a

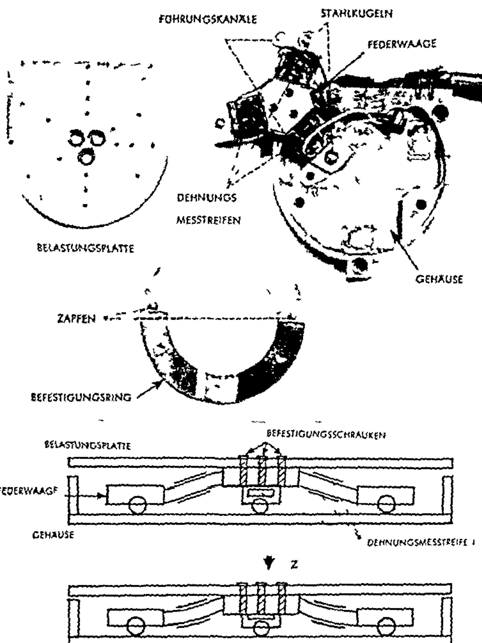




b

Abb ? a Messplatte zusammengesetzt wie sie im Absatz des Schuhes zur Verwendung kommt

b Messplatte mit demontierter Belastungsplatte die mit drei Schrauben im Zentrum der Federwaage fixiert wird Die kleinen Bohrlocher in der Belastungsplatte dienen zur Testbelastung



c zeigt die Messplatte in ihre Bestandteile zerlegt Die Federwaage ist nach Abschrauben des halbmondformigen Befestigungsringes aus dem Gehause herausgehoben worden An der Unterseite dieses Ringes befinden sich zwei Zapfen die in zwei Fuhrungskanalen der Federwaage versenkt deren Lage im Gehause bestimmen Auf den drei Armen der Federwaage sind die aufgeklebten Dehnungsmesstreifen ersichtlich Entsprechende Dehnungsmesstreifen befinden sich auch auf der Unterseite der Arme

d veranschaulicht schematisiert das Prinzip der Federwaage im unbelasteten Zustand im Frontalschnitt

e zeigt schematisiert die Deformierung der Federarme bei Belastung mit der Kraft Z

Die zur Durchführung der vorliegenden Arbeit verwendeten zwei Messplatten (no 1 = rechter Fuss nr 2 = linker Fuss) waren neue Exemplare gleicher Konstruktion Sie unterschieden sich vom ersten Exemplar (Wetzenstein) durch eine geringere Biegbarkeit der Federwaage (siehe Seite 94)

Die Errechnung von y und x war durch eine neukonstruierte elektronische Brucke vereinfacht worden (siehe Seite 90) Sie ergab den z Wert direkt in Kilopond und die Werte fur die Zahler der oben auf Seite 18 genannten Formeln d h fur $U_1 - \frac{1}{2}(U_2 + U_3)$ und $\frac{\sqrt{3}}{2}(U_2 - U_3)$ in Form von fotografisch (Schreiber Typ Visicorder Oscillograph) registrierten Kurven (Abb 3) Mit Hilfe dieser Werte konnten dann y und x den genannten

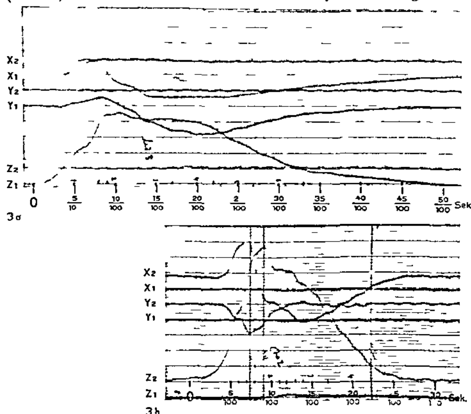


Abb 3 a Originalkurve mit dem Ausschlagen fur z und fur die Berechnung von y und x (z_1 y_1 und x_1 = rechter Fuss z y und x = linker Fuss) bei *Gang in* 4 km/h auf der rollenden Gehbahn (protokoll 173/6 Korpergewicht 72 8 kg)

b Originalkurve der gleichen Versuchsperson bei Gang in 8 km/h auf der rollenden Gehbahn Die langslaufenden Referenzlinien liegen in Abstanden von 2 mm von einander Die senkrechten Zeitmarkierungslinien entsprechen 1/100 Sekunden Entlang dieser wurden die Ausschlage der Kurven mit Hilfe eines durchsichtigen Lineales abgelesen Die parallel zu ihnen befindlichen etwas kraftigeren Linien sind als Hilfslinien fur die Ablesung von maximalen Ausschlagen an solchen Stellen eingezeichnet worden wo maximale Ausschlage nicht mit Zeitmarkierungslinien zusammenfallen

Formeln gemäss berechnet werden Der Kalibrierungsfaktor $\frac{h}{E}$ fiel fort da die Amplituden für die Ausschläge z y und x bei gegebener Belastung der Messplatte einstellbar waren

Der Transport des Schreiberfilmes wurde mit der hochsten Geschwindigkeit eingestellt (53 cm/Sek), um die grösst mogliche Genauigkeit bei der Ablesung der Kurven zu erzielen Ein Zeitschreiber markierte jede hundertstel Sekunde mit einer querlaufenden Linie Ein System von längslaufenden Referenzlinien erleichterte die Bestimmung der 0 Linien der Galvanometer (Abb 3)

Die Ablesung der Galvanometerausschlage erfolgte mit Hilfe eines durchsichtigen Millimetermasses entlang der Zeitmarkierungslinien

Die Ablesungsintervalle betrugen höchstens 5/100 Sek Die letzte Zeitmarkierung bei der z noch 0 betrug war der Ausgangspunkt der Zeitrechnung *Daruber hinaus erfolgten Ablesungen mit kürzeren Intervallen* in den Bereichen der Kurven, denen in dieser Arbeit besonderes Interesse gewidmet wurde Dies geschah auch vor und nach maximalen Ausschlagen der einzelnen Kurven Wenn der maximale Ausschlag nicht in Hohe einer Zeitmarkierungslinie lag wurde eine parallele Hilfslinie eingezeichnet (Abb 3)

Die z y und x Werte bildeten das Ausgangsmaterial fur die Bearbeitung der Belastungsmessungen

2 MONTAGE DER MESSPLATTE IM SCHUH

Eine Serie von Halbschuhen mit Ledersohlen war speziell für die Versuche hergestellt worden Der Leisten gewährte die gerade Innenlinie und gab guten Bewegungsraum für die Zehen Der Absatz war mit einer Aussparung versehen in welche die Messplatte versenkt wurde (Abb 4)

Ihre Montage erfolgte mit Hilfe einer Befestigungsanordnung wie sie in der Abb 5 ersichtlich ist Diese Befestigungsanordnung bestand aus einer in alle Ebenen des Raumes verstellbaren Leichtmetallplatte

Jeder Schuh war mit einer solchen Befestigungsplatte versehen Um eine



Abb 4 Experimentschuh mit eingebau ter Messplatte

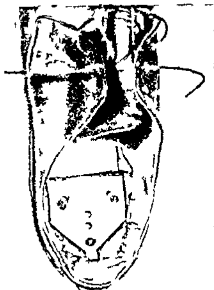


Abb 5 Experimentschuh mit eingebau ter Fixationsplatte Sie ist in alle Eb ne des Raumes verstellbar und bestimmten Massen entsprechend im Verhaltnis zum Schuh eingestellt worden Auf ihr wird die Messplatte mit drei Schrauben befestigt

vergleichbare Lage der Messplatte in den verschiedenen Schuhen zu erzielen waren die Befestigungsplatten folgenden Normen gemass montiert

Der Mittelpunkt der Befestigungsplatte sollte sich in gleichgrossen Abstanden von der Innen und Aussenseite des Absatzes befinden und sein Abstand von dem am weitesten dorsal liegenden Punkt des Absatzes sollte

in sämtlichen Schuhen einem bestimmten Mass entsprechen *Die Einrichtung der Längsaxe der Befestigungsplatte geschah mit Hilfe eines auf die vordere Kappe des Schuhes markierten Richtpunktes und eines Richtinstrumentes (Abb 6) Der Richtpunkt wurde folgendermassen ermittelt* Jeder

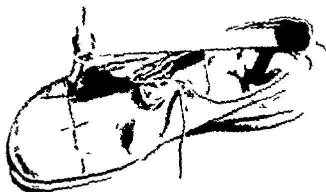


Abb 6 Richtinstrument fur die Einstellung der Fixationsplatte im Hinblick auf ihre Längsachse

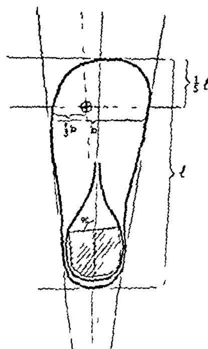


Abb 7 Ermittelung des Richtpunktes fur die Einrichtung der Langsachse der Fixationsplatte mit Hilfe empirisch gewonnener Masse Auf der Winkelhalbierenden zwischenden tangierenden Linien an der Aussen und Innenseite der Sohle und des Absatzes wird die Lange der Sohle abgetragen Auf 1/5 dieser Lange wird eine im 90 Winkel zu ihr laufende Linie eingezeichnet Auf dieser Linie findet man den Richtpunkt auf der Grenze vom ausseren zum mittleren Drittel der Breite der Sohle

Schuh wurde auf ein Blatt Papier gelegt und tangierende Linien entlang der Aussen und Innenseite der Sohle und des Absatzes aufgezeichnet (Abb 7) Dadurch erhielt man einen nach vorne (im Sinne des Schuhes) gerichteten Winkel In diesen wurde die Winkelhalbierende eingetragen und auf ihr die Lange der Schuhes abgezeichnet Auf ein Fünftel der Lange dieser Linie in Bezug auf den Schuh von vorne gerechnet wurde eine Linie im Winkel von 90° eingetragen und auf ihr die Breite der Sohle in ihrer Hohe abgezeichnet Auf ein Drittel dieser Linie von der Aussenseite der Sohle gerechnet lag der Richtpunkt Die Überfuhrung des Richtpunktes von der Zeichnung auf das Oberleder der vorderen Kappe erfolgte mit Hilfe eines durchsichtigen Lineales Die querlaufende Linie wurde auf die Kappe eingezeichnet und ein Drittel ihrer Lange mit einer Schublehre abgemessen Diese Masse wurden empirisch ermittelt nachdem eine Messplatte versuchsweise in einen Absatz montiert worden war

Die Einstellung zur Horizontalen erfolgte mit Hilfe einer Wasserwaage

Die Hohe der Befestigungsplatte wurde so gewahlt, dass die Belastungsflache der Messplatte c a 20 mm über dem Niveau der Belastungsflache der vorderen Sohle lag

Bei der Überführung der Messplatte von einem Schuh zum anderen war in dieser Weise ihre Lage gegeben und brauchte nicht erneut eingestellt zu werden

Wie aus dem hier gesagten hervorgeht musste mit Variationen in der Lage der Messplatte zwischen den verschiedenen Schuhen gerechnet werden Die verwendeten Referenzpunkte für die Zentrierung der Messplatte waren auf Grund der komplizierten und nicht beständigen Form der Schuhe nicht ganz eindeutig Hier muss auch beachtet werden dass die Belastungsplatte mit der Federwaage im Gehause nicht vollständig fest fixiert lag sondern eine geringe Beweglichkeit besass Diese betrug

Rotation = 1 3°
Verschiebbarkeit in der Y Achse = 0 6 mm
Verschiebbarkeit in der X Achse = 0 5 mm

koordinatographisch gemessen

Diese Beweglichkeit der Belastungsplatten im Gehäuse hatte technische Ursachen Eine Konstruktion mit fest verankerter Federwaage hatte kompliziertere Deformierungen der Federarme zur Folge gehabt und messtechnische Nachteile geboten Die hier gewahlte Konstruktion war zuverlassiger

3 EINSTELLUNG UND FORTLAUFENDE KONTROLLE DER APPARATUR

Die Grösse der Ausschläge für z und der für die Berechnung von y und x waren von der Einstellung der Brückenkreise und der gewählten Amplitude abhängig Diese Einstellung geschah wie folgt

Die Messplatte bzw der Schuh mit einmontierter Messplatte wurde in eine der Dezimalwaage gemass konstruierten Belastungswaage gelegt mit welcher gewunschte Belastungen zur Testung angelegt werden konnten (Abb 8) Die Waage war mit einem Momentarm versehen mit welchem die gewunschte Belastung mit einem zehnten Teil des Gewichtes erzielt werden konnte

Zur Durchfuhrung von Testbelastungen war die Belastungsflache der Messplatte mit einem System von Bohrlochern versehen worden deren Lage

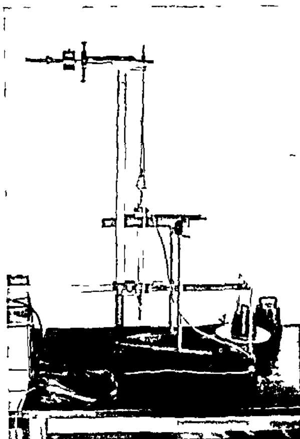
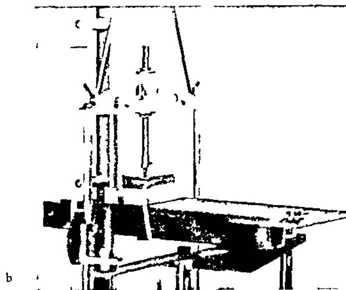
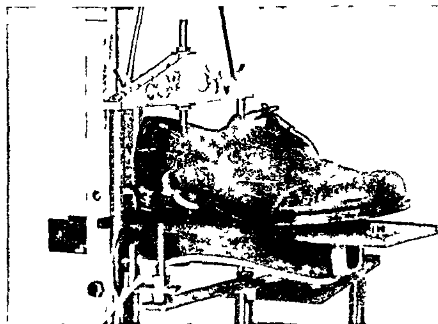


Abb 8 a



b



c

Abb 8 a Waage zur Testbelastung der Messplatte Ein konischer Stahlstab wird mit Hilfe eines hangenden Systemes in die Bohrlocher der Belastungsplatte gesenkt und dann wird der Hebelarm der Waage (1 10) mit den gewunschten Gewichten belastet (b Testung der Messplatte vor und c nach Montage im Schuh)

beziehungen zur X und Y Achse bekannt waren Die Belastung konnte dadurch an definierten Punkten erfolgen (Abb 4)

Nach 0 Stellung der Bruckenkreise fur die drei Ausschlage wurde eine Testbelastung von 50 kp auf den Mittelpunkt der Me splatte gelegt Nun erfolgte die Wahl der Amplitude fur den z Ausschlag mit Hilfe eines Potentiometers Im Hinblick auf die Breite des Schreiberpapieres (15 cm) fiel die Wahl auf einen Ausschlag von 1 mm = 1 kp d h 50 mm bei der verwendeten Testbelastung Es galt nun die Amplituden für die Ausschlage zur Errechnung von y und x entsprechend einzustellen Hierzu wurde die Testbelastung auf einen Punkt 10 mm vom Mittelpunkt entfernt in Richtung der Y Achse gelegt Um den richtigen y Wert d h 10 mm in diesem Falle aus der vorher genannten Formel fur y (siehe Seite 18) zu erhalten bedurfte es eines Ausschlages von 50 mm Der Faktor L war 10 Nun galt

$$y = \frac{50}{50} \cdot 10 = 10 \text{ mm}$$

In eben derselben Weise wurde die Amplitude fur den Ausschlag zur Errechnung von x eingestellt nachdem die Testbelastung auf einen Punkt 10 mm vom Mittelpunkt in Richtung der X Achse gelegt worden war

Nach ausgefuhrter Amplitudeneinstellung galt es nun das Gleichgewicht zwischen den Bruckenkreisen zu kontrollieren d h es war notwendig festzustellen ob die drei Ausschlage bei Testbelastungen von zwei gleichwertigen Punkten z B 10 mm vor und 10 mm hinter dem Mittelpunkt in Richtung der X Achse (— x und + x) gleich gross waren Je zwei gleichwertige Punkte in Richtung der X und Y Achse wurden nacheinander mit 50 kp belastet und die Ausschlage wurden verglichen Entstanden ungleiche Ausschlage konnte das Gleichgewicht mit Hilfe von Potentiometern erneut hergestellt werden In der Praxis kam dies nur selten vor

Die Einstellung der Apparatur bestand demnach aus

0 Stellung der Bruckenkreise

Amplitudeneinstellung

Balanceeinstellung zwischen den Bruckenkreisen

Vor und nach jeder Versuchsperson (Versuchsserie) erfolgte eine Kontrolle der Apparatur diesem System gemass mit einer Testbelastung von 50 kp auf 4 Punkten mit Abstanden von je 10 mm vom Mittelpunkt in Richtung der Y und X Achse

4 DER MESSFEHLER DER APPARATUR

Zur Untersuchung des Messfehlers der Apparatur wurden eine Reihe von Testbelastungen in folgender Weise ausgeführt

Zunachst erfolgte die Finstellung der Apparatur in der im vorigen Kapitel beschriebenen Weise Danach belastete man den Mittelpunkt der Messplatte bis 150 kp mit Intervallen von 10 kp Zwischen jeder Belastungsänderung erfolgte eine vollständige Entlastung der Waage wobei die Ausschlage (z y x) stets zu O Linie zuruckkehrten Unmittelbar darauf geschah eine Wiederholung des Versuches dieses Mal umgekehrt d h von 150 bis 0 kp

Nach erneuter Kontrolle der Einstellung wurde in gleicher Weise ein weiteres Bohrloch belastet und so insgesamt 41 Bohrlocher getestet Die Lage der Bohrlöcher auf der Belastungsplatte ist in der Abb 9 ersichtlich

Betrachtet man das Resultat der Belastungsserien der einzelnen Punkte (=Bohrlocher) findet man wie erwartet einen klaren linearen Zusammenhang zwischen Belastung und Grosse der Ausschlage (Diagram 1) Überschreitet die Belastung eine bestimmte Grenze entstehen Abweichungen von

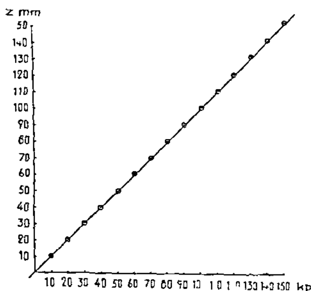


Diagram 1 zeigt den linearen Zusammenhang zwischen z Ausschlagen und Belastung des Mittelpunktes (Punkt 1 Abb 9) der Messplatte fur den rechten Fuss fur 2 aufeinander folgende Serien mit Belastungen von 0 bis 150 kp (Serie 1 mit und Serie 2 m t o gekennzeichnet) D r arithmetische Mittelwert der Abweichungen vom erwarteten Wert ist aus Tabelle 1 ersichtlich (+0 53)

der Linearität Das hängt mit der Konstruktion der Messplatte zusammen Bei zu hoher Belastung legt sich die Belastungsplatte der Kante des Gehäuses an wodurch ein Teil der Belastungskraft verbraucht und nicht in der Federwaage registriert wird Je weiter der Kraftangriff sich vom Mittelpunkt der Belastungsplatte entfernt desto niedriger liegt auf Grund der Verlängerung des Hebelarmes die Grenze der Linearität Testbelastungen zeigten dass der zentrale Bereich der Messplatten mit einem Radius von 10 mm um den Mittelpunkt bis zu 150 kp ohne wesentliche Abweichungen von der Linearität belastet werden konnte Innerhalb eines Radius von 15 mm lag die Grenze bei etwa 80 kp und innerhalb eines Radius von 20 mm bei etwa 60 kp Diese Werte wurden von keiner Versuchsperson erreicht Eine Betrachtung der Resultate der Testbelastungen ergab folgendes

1) Die gemessenen z y und x Werte wiesen systematische Abweichungen von den richtigen erwarteten der aufgelegten Belastung entsprechenden Werten in den verschiedenen Serien auf Eine statistische Analyse dieses Phänomenes war nicht erforderlich da es deutlich hervortrat Man hatte oft Serien mit 29 Belastungen (von 0 bis 150 kp und zurück zu 0 kp) bei denen alle Abweichungen 0 oder positiv bzw 0 oder negativ waren Die durchschnittlichen Abweichungen waren relativ gering Als Beispiel dafür folgt hier eine Tabelle (1) mit arithmetischen Mittelwerten der Abweichungen für z y und x von den erwarteten Werten (die mit z_r y_r und x_r bezeichnet werden) an den 5 zentralen Bohrlöchern (punkt 1—5, Abb 9) der Messplatte für den rechten Fuss

Testpunkt (Abb 9)	Anzahl der Bestimmungen	$\overline{z}-\overline{z}_r$ (kp)	$\overline{y}-y_r$ (mm)	$\overline{x}-x_r$ (mm)
1	30	+ 0 53	+ 0 065	+ 0 005
2	29	+ 0 15	+ 0 23	— 0 07
3	29	— 0 98	+ 0 06	+ 0 21
4	29	+ 0 80	— 0 11	— 0 005
5	29	+ 0 42	+ 0 24	— 0 23

Tabelle 1
Mittlere Werte der Abweichungsquadrate von den erwarteten Werten für z y und x bei Testbelastungen von 0 bis 150 kp der Messplatte 1 (Messplatte für den rechten Fuss)

Die Ursache dieser systematischen Abweichungen konnen hauptsachlich in dem Einstellungsverfahren der Messbrucken gesucht werden

(ii) Über den systematischen Fehler hinaus kommen gewisse Variationen in den Serien hervor die als zufallige Fehler der Messungen angesehen werden konnen

Die genannten Fehlerkomponenten konnen schematisch folgendermassen dargestellt werden

Wenn man nach Einstellung der Apparatur eine Serie von Messungen an einer Versuchsperson durchfuhrt kann ein isolierter Messwert sagen wir ein z Wert symbolisch mit

$z = z_r + e_r + e_t$

bezeichnet werden z_r bezeichnet den Wert den man erhalten hatte wenn die Registrierung ohne Einstellungsfehler und zufallige Fehler erfolgt ware e_r bezeichnet den systematischen Einstellungsfehler fur die Serie und e_t den zufalligen Fehler fur diese Registrierung Um die Grossenordnung von e_r und e_t zu bestimmen wurde folgendermassen verfahren

Nach Einstellung der Messbrucken aber vor den Messungen an Versuchspersonen wurden wie bereits gesagt Testbelastungen mit 50 l p an 4 Punkten (Punkt 2 3 4 und 5) ausgefuhrt 25 solche Serien fur jede Messplatte sind naher analysiert worden

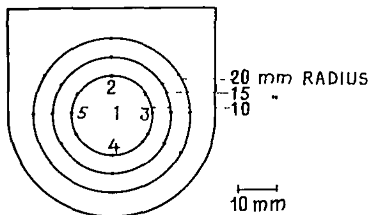


Abb 9 Verteilung der Bohrlocher auf der Belastungsplatte zur Testbelastung

	Freiheits grade	z Mess platte 1	z Mess platte 2	y Mess platte 1	y Mess platte 2	x Mess platte 1	x Mess platte 2
1) Mittelwert der Abweichungsquadrate zwischen den Serien	24	1 031	0 922	0 015	0 029	0 009	0 018
2) Mittelwert der Abweichungsquadrate innerhalb der Serien	75	0 073	0 121	0 039	0 037	0 019	0 074
3) Arithmetischer Mittelwert fur samtliche Messungen		50 255	—49 775	0 109	0 021	0 006	—0 074
4) t	24	2 5	—2 3	8 9	1 2	0 6	—5 4

Tabelle 2

Varianzanalyse und t — Test von Testbelastungen mit 50 kp auf 4 Punkten um den zentralen Bereich der Messplatten (25 Serien je Messplatte)

Tabelle 2 ergibt das Resultat der Analyse Für die Variabel *z stellte man* folgendes fest

Die Varianz des zufalligen Fehlers wurde fur die Messplatte 1 zu 0 073 und fur die Messplate 2 zu 0 121 geschatzt Die dazugehorigen Standardabweichungen waren 0 27 bzw 0,35 Die Bedeutung der Einstellungsfehler war von der Art der Untersuchung abhängig Handelte es sich um eine Serie von Messungen an einer Versuchsperson unter gleichen Versuchsbedingungen, belasteten die Einstellungsfehler diese Serie Handelte es sich um zwei verschiedene Experimente wie z B Gang in 4 km/h und 8 km/h mit einer Bestimmung von Differenzen fur die Variabel z verschwant die Bedeutung der Einstellungsfehler (unter der Voraussetzung dass diese Fehler im Verlauf der Messungen unverandert blieben) Haben wir eine Gruppe von Versuchspersonen und betrachten die Variation der erhaltenen z Werte *zwischen Personen treten die Einstellungsfehler als zufälliger* Fehler auf da fur jede Versuchsperson eine erneute Einstellung erfolgte

Wie bereits genannt wurden 25 Testserien per Messplatte analysiert Betrachtet man die 25 Einstellungsfehler , ergeben sich folgende Fragen

(i) unterscheiden sich die Einstellungsfehler durchschnittlich von 0?

(ii) zeigen die Einstellungsfehler eine Variation um den erwarteten Wert? Wie gross ist diese Variation?

Die erste Frage konnen wir mit Hilfe der arithmetischen Mittelwerte fur die ganze Serie und den dazugehorigen t — Testen (Tabelle 2) beantworten Fur die Messplatte 1 ist der Schatzwert fur den Durchschnitt der Einstellungsfehler 0 255 (signifikant) fur die Messplatte 2 hingegen — 0 225 (signifikant)

Den ersten Teil der zweiten Frage (ii) konnen wir mit Ja beantworten da der Mittelwert der Abweichungsquadrate zwischen Serien verglichen mit dem Mittelwert der Abweichungsquadrate innerhalb der Serien gross war (signifikant)

Die Varianz der Einstellungsfehler (zweiter Teil der Frage (ii)) kann mit Hilfe der in der Tabelle 2 ersichtlichen Data geschatzt werden Das Resultat fur Messplatte 1 wird 0 24 und fur Messplatte 2 = 0 20 mit den dazugehorigen Standardabweichungen von 0 49 bzw 0 45

Die Variabel y betreffend wird die Varianz des zufalligen Fehlers fur Messplatte 1 auf 0 039 und fur Messplatte 2 auf 0 037 mit dazugehorigen Standardabweichungen von 0 20 bzw 0 19 geschatzt Der Durchschnitt der Einstellungsfehler war für beide Messplatten positiv signifikant fur nr 1 dagegen nicht signifikant fur Messplatte 2 Die Schatzwerte waren fur Messplatte 1 = 0 109 und fur Messplatte 2 = 0 021 Wie ersichtlich sind sie von geringer Grosse Eine Variation der systematischen Einstellungsfehler fur y konnte nicht nachgewiesen werden

Die Varianz des zufalligen Fehlers fur die Variabel x wird fur die Messplatte 1 auf 0 019 und fur nr 2 auf 0 074 geschatzt Die dazugehorigen Standardabweichungen waren 0 14 bzw 0 27 Der Schatzwert fur den Durchschnitt der Einstellungsfehler wird fur Messplatte 1 positiv 0 006 und fur Messplatte 2 negativ — 0 074 signifikant nur fur Messplatte 2 Entsprechend den Verhaltnissen fur die Variabel y ist die Grossenordnung der Abweichungen gering Es konnte auch fur die Variabel x keine Variation fur die systematischen Einstellungsfehler nachgewisen werden

Die Schatzungen des Messfehlers mit Hilfe dieser Untersuchungen representieren eher eine untere Grenze der Grossenordnung des Fehlers da nur eine Belastungsquantitat (50 kp) und nur 4 zentral gelegene Messpunkte verwendet wurden

III

	Freiheits grade	z Mess platte 1	z Mess platte 2	y Mess platte 1	y Mess platte 2	x Mess platte 1	x Mess platte 2
1) Mittelwert der Abweichungsquadrate zwischen den Serien	24	1 031	0 922	0 015	0 029	0 009	0 018
2) Mittelwert der Abweichungsquadrate innerhalb der Serien	75	0 073	0 121	0 039	0 037	0 019	0 074
3) Arithmetischer Mittelwert fur samtliche Messungen		50 255	—49 775	0 109	0 021	0 006	—0 074
4) t	24	2 5	—2 3	8 9	1 2	0 6	—5 4

Tabelle 2

Varianzanalyse und t — Test von Testbelastungen mit 50 kp auf 4 Punkten um den zentralen Bereich der Messplatten (25 Serien je Messplatte)

Tabelle 2 ergibt das Resultat der Analyse Für die Variabel z stellte man folgendes fest

Die Varianz des zufalligen Fehlers wurde fur die Messplatte 1 zu 0 075 und fur die Messplate 2 zu 0 121 geschatzt Die dazugehorigen Standardabweichungen waren 0 27 bzw 0 35 Die Bedeutung der Einstellungsfehler war von der Art der Untersuchung abhangig Handelte es sich um eine Serie von Messungen an einer Versuchsperson unter gleichen Versuchsbedingungen belasteten die Einstellungsfehler diese Serie Handelte es sich um zwei verschiedene Experimente wie z B Gang in 4 km/h und 8 km/h mit einer Bestimmung von Differenzen fur die Variabel z, verschwant die Bedeutung der Einstellungsfehler (unter der Voraussetzung dass diese Fehler im Verlauf der Messungen unverandert blieben) Haben wir eine Gruppe von Versuchspersonen und betrachten die Variation der erhaltenen z Werte zwischen Personen treten die Einstellungsfehler als zufalliger Fehler auf da fur jede Versuchsperson eine erneute Einstellung erfolgte

Die unter zweitens genannten Fehler hatten auch verringert werden können. Man begegnet hier jedoch prinzipiellen Schwierigkeiten in der komplizierten und relativ unbeständigen Form des Schuhes, welche eine Bestimmung der Referenzpunkte nur in begrenztem Umfange zulässt.

Die unter drittens genannten Fehler, die mit der Lage der Ferse auf der Messplatte zu tun haben, entzogen sich einer Kontrolle. Es ist schwer zu sehen, in welcher Richtung eine Lösung dieses Problemes gesucht werden könnte.

Zusammenfassend kann festgestellt werden, dass der Methodenfehler der Apparatur hätte verringert werden können. Dies würde natürlich einen bedeutenden technischen Einsatz erfordert und die Metode komplizierter gemacht haben. Die Frage, ob eine solche technische Verbesserung wertvoll sein würde, kann erst beantwortet werden, nachdem man eine Auffassung über die Grösse der biologischen Variationen gewonnen hat. Sollten diese Variationen im Verhältnis zum Methodenfehler gross sein, würde eine Verringerung des technischen Methodenfehlers die Anwendbarkeit der hier dargelegten Methode nicht wesentlich beeinflussen.

Auch wenn es möglich gewesen wäre, die genannten Methodenfehler zu eliminieren, wäre eine weitere Schwierigkeit bei der Deutung des biologischen Inhaltes der registrierten Werte bestehen geblieben. Hier muss zunächst hervorgehoben werden, dass die Messresultate sich auf das Koordinatensystem der Messplatte bezogen und nicht direkt auf anatomische Referenzpunkte. Die Lage des Angriffspunktes der Kraftresultante war einerseits von der Lage der Ferse auf der Messplatte und anderseits von der anatomischen Beschaffenheit und Funktion des Bewegungsapparates abhängig. Für eine Lagebestimmung der Ferse auf der Messplatte, d. h. zu ihrem Koordinatensystem, bedurfte es definierter anatomischer Referenzpunkte. Solche Referenzpunkte liessen sich in Wirklichkeit nicht eindeutig bestimmen.

Die unzureichende Orientierung der Ferse zum Koordinatensystem der Messplatte kann auch für die Beurteilung der Quantität der Kraftresultante von Bedeutung gewesen sein. Je grösser der auf der Messplatte ruhende Teil der Fusses war, desto grösser war der Teil der gesamten Fussbelastung, der registriert wurde.

Schliesslich war für die Bewertung der Resultate auch die Grösse der Ferse von Bedeutung. Ein und derselbe y- oder x-Wert hatte in Abhängigkeit von der Grösse der Ferse unterschiedlichen Wertinhalt.

Alle hier genannten Schwierigkeiten einer biologischen Deutung der Resultate von Messungen entscheiden jedoch nicht ohne weiteres den praktischen Wert der Methode.

Die Durchführung der Versuche

Nach Kontrolle der Schnürung und der Passform der Schuhe wurde die Versuchsperson auf die ruhende Gehbahn gestellt. Der Start der Gehbahn erfolgte dann mit einer Geschwindigkeit von 4 km/h (Abb. 10).

Das Gehen auf einer rollenden Bahn bedarf gewisser Übung. Die sich nach hinten bewegende Unterlage verursacht eine Tendenz der Versuchspersonen nach vorne zu fallen und auf den Zehen zu gehen. Alle Versuchspersonen überwanden diese Tendenz nach etwa 1 bis 2 Minuten und empfanden das Gehen als natürlich, d. h. dem Gehen auf fester Unterlage ent



Abb. 10. Versuchsperson während eines Gangexperimentes auf der rollenden Gehbahn

prechend Doch kann die Moglichkeit eines Einflusses der speziellen Ver altnisse infolge der Gehbahn auf die Belastung des Fusses nicht ausge hlossen werden

Wahrend des Eingehens war die elektronische Apparatur bereits einge chaltet und die Registrierung der Fersenbelastung konnte jederzeit mit nem elektrischen Kontakt ausgelost werden Der Start und der Abschluss er Registrierung geschah ohne dass die Versuchsperson im Gehen gestort rurde Es erfolgten keine Anweisungen betreffend der Schrittlange bzw er Anzahl der Schritte per Zeit Die individuelle Gangart sollte so wenig rie moglich beeinflusst werden

Nachdem sich der Gangrhythmus stabilisiert hatte wurden durchschnittlich aufeinander folgende Fersenbelastungen je Fuss registriert

Ausser diesem Experiment mit der bequemen Ganggeschwindigkeit von km/h wurde ein weiteres mit der hohen Ganggeschwindigkeit von 8 km/h usgefuhrt Darüber hinaus wurden zwei Experimente in 4 km/h vorgenom nen bei denen die Versuchspersonen eine maximale Auswartsdrehung zw eine maximale Einwartsdrehung der Fusse anstrebten Es war ie Absicht mit diesen Experimenten den Einfluss von Anderungen ler Fusstellung auf die Fersenbelastung zu prufen Karpovich und Vilklow hatten bei ihren Winkelmessungen zwischen Ferse und Unter chenkel gefunden dass eine Auswartsstellung des Fusses eine Valgusstel ung der Ferse und umgekehrt eine Einwartsstellung des Fusses eine Varus *tellung der Ferse verursacht Elftman und Elftman und Manter* 1934) fanden bei ihren Untersuchungen der Fussbelastung dass die Wan lerungsrichtung des Angriffspunktes der Kraftresultante (vertikale Kraft) on der Stellung des Fusses abhangig war Bei Auswartsstellung richtete ich der Verlauf im Verhaltnis zum Fuss nach innen und bei Einwarts tellung nach aussen

Die genannten 4 Experimente wurden mit kurzen Pausen fur Protokol ierung nacheinander auf der rollenden Gehbahn in folgender Reihenfolge usgefuhrt ohne dass die Versuchsperson sie verliess

Habitueller Gang mit einer Geschwindigkeit von 4 km/h

Gang mit angestrebter maximaler Auswartsrichtung der Fusse in 4 km/h

Gang mit angestrebter maximaler Einwartsrichtung der Fusse in 4 km/h

Habitueller Gang mit einer Geschwindigkeit von 8 km/h

Im Weiteren werden die Experimente wie folgt bezeichnet

A = Habitueller Gang 4 km/h

B = Habitueller Gang 8 km/h

C = Auswartsstellung 4 km/h

D = Einwartsstellung 4 km/h

Die Darstellung der Fersenbelastungsdiagramme und die Wahl der abhängigen Variabeln

Für jede Fersenbelastung erhielt man, wie bereits beschrieben, fortlaufende Angaben über die Lage des Angriffspunktes und die Grösse der senkrecht gegen die Absatzebene des Schuhes gerichteten Kraftresultante im Verhältnis zum Koordinatensystem der Messplatte als Funktion der Zeit

Die Wanderung des Angriffspunktes dieser Kraftresultante während einer Fersenbelastung über die Messplatte kann in Form einer Kurve dargestellt werden hier im Folgenden als Fersenbelastungsdiagram (Fbd) bezeichnet

Für jede Fersenbelastung hat man die z y, und x Werte als Funktion der Zeit Der Verlauf der Fersenbelastung konnte nun mit Hilfe von drei zweidimensionellen Diagrammen dargestellt werden Eine solche Darstellung wäre jedoch weniger übersichtlich gewesen Um besser die Grosse und die Lage der Kraftresultante als eine Funktion der Zeit anschaulich zu machen verfuhr man wie folgt

Es wurde ein rechtwinkeliges Koordinatensystem verwendet in dem die X Koordinate der X Achse der Messplatte (Langsachse) und die Y Koordinate der Y Achse der Messplatte (Querachse) entsprach (Abb 11) Es muss hier erwähnt werden, dass die umgekehrte Lage der Koordinaten verglichen mit der gebräuchlichen gewählt wurde weil in Publikationen ähnlicher Messapparaturen die Langsachse meistens als X Achse bezeichnet wurde Weiter ist es wichtig zu beachten, dass die Orientierung der Y Koordinate zwischen Diagrammen für den linken und rechten Fuss verschieden war Für beide Füsse war die positive Richtung von Y gleich bedeutend mit der lateralen Seite der Ferse Dahingegen war die Orientierung der X Koordinate für beide Füsse mit der positiven Richtung von X zur Fusspitze hin gleich

Die Wanderung der Kraftresultante während einer Fersenbelastung

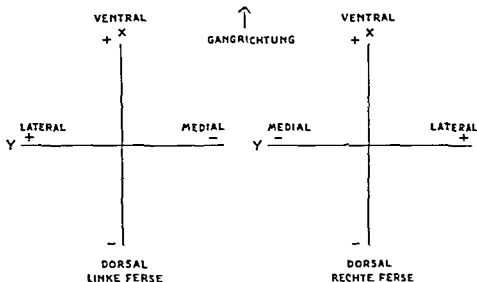


Abb 11 Das Koordinatensystem der Fersenbelastungsdiagramme (Fbd) Die X Koordinate entspricht der X Achse der Messplatte d h ihrer Langsaxe und die Y Koordinate der Y Achse d h der Querachse der Messplatte Die Orientierung der Y Koordinate wurde so gewahlt dass ein negativer Wert sich im Prinzip medial zum Fuss verhalt Die Orientierung der X Koordinate ist die gleiche fur den linken und den rechten Fuss

beschrieb eine Kurve im X Y Koordinatensystem Diese Kurve erhielt man durch Eintragung der Angriffspunkte der Kraftresultante mit Hilfe der x und y Werte für jeden abgelesenen Zeitpunkt (Abb 12) Durch Verbindungslinien zwischen diesen Punkten entstand dann die Kurve Um eine Auffassung uber den Zeitverlauf zu erhalten wurde jeder mit einem Zeitablauf von 5/100 Sek zusammenfallende Punkt mit einem durchgezeichneten und ubrige Punkte mit gestrichelten Ringen markiert Die Quantitat der Belastung in % des Korpergewichtes ausgedruckt war aus Ziffern ersichtlich Der Ablesungspunkt in welchem die registrierte Belastung ihr Maximum erreichte erhielt eine Markierung mit doppelten Ringen

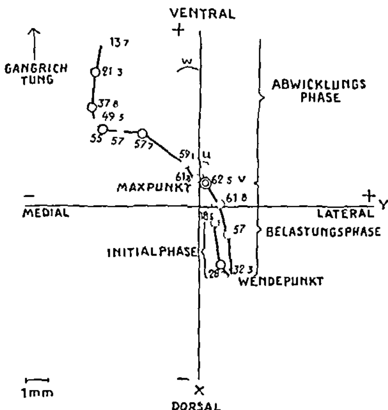


Abb 12 Fersenbelastungsdiagram (Fbd) eines rechten Fusses Mit Hilfe der y und x Werte wurden die Angriffspunkte der Kraftresultante fur die Zeitpunkte der Ablesungen in das Diagram eingetragen Durch Verbindungslinien zwischen den Punkten ist der zeitliche Zusammenhang ersichtlich Zwischen zwei durchgezeich neten Ringen liegt ein Zeitablauf von 5/100 Sekunden Das Maximum der registrier *ten Kraft wird mit einem doppelten Ring gekenn eichnet Punkte die zeitlich* zwischen 5/100 Sekunden liegen werden mit gestrichelten Ringen gekennzeichnet

u = *Abstand des* Maxpunktes *von der* X Koordinate

v = *Quantitat der* Maxpunktsbelastung *in* % des Korpergewichtes

w = *Winkel zwischen einer Verbindungslinie vom* Wendepunkt *zum* Maxpunkt *und* der X Koordinate

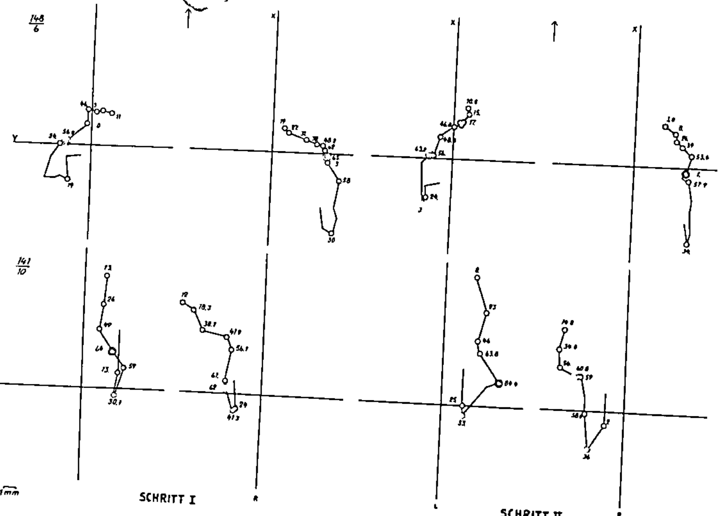
Um ein Bild über das Aussehen der Fersenbelastungdiagramme (Fbd) zu erhalten sind in Abb 13 solche von 5 Versuchspersonen bei habituellem Gang in 4 km/h auf der rollenden Gehbahn zusammengestellt worden Die Auswahl dieser Versuchspersonen geschah in folgender Weise Zwei von ihnen wurden vom Resultat der klinischen Untersuchung ausgehend so gewählt dass die eine (Prot No 148/6) eine suspekte Varusstellung und die andere (Prot No 141/10) eine suspekte Valgusstellung der Ferse repräsentierte Es handelt sich wie bereits besprochen um geringe durch Besichtigung eingeschätzte Abweichungen der Ferse von senkrechter Stellung (siehe Seite 37) denen eine pathologische Bedeutung nicht ohne weiteres zugeschrieben werden konnte Die drei übrigen Versuchspersonen wurden dem Zufall gemäss ausgewählt

Die Fbd für jede Ferse von zwei aufeinander folgenden Schritten sind in Abb 13 nebeneinander ersichtlich Trotz Variationen zwischen den Fbd der gleichen Ferse vom einen Schritt zum anderen und zwischen Fersen lassen sich Ähnlichkeiten erkennen Zunächst folgt hier eine Beschreibung der bei allen Registrierungen von Fersenbelastungen bei habituellem Gang vorkommenden Grundform der Fbd

Wie aus den Beispielen ersichtlich wanderte der Angriffspunkt der Kraftresultante vom ersten Kontakt zwischen Schuh und Unterlage nicht im Sinne der Abwickelung des Fusses unmittelbar nach vorn sondern nahm erst einen dorsal gerichteten Verlauf (Abb 12 und 13) Nach etwa 5/100 Sekunde wendete sich der Verlauf nach vorn Diese initiale dorsal gerichtete Phase war eine konstante Erscheinung Sie wird hier als Initialphase bezeichnet Carlsoo Eberhart & Inman und Harper und Mitarbeiter beobachteten bei ihren Untersuchungen der Kräfte zwischen Fuss und Unterlage eine horizontale dorsal gerichtete Kraft unmittelbar nach dem Aufsetzten der Ferse Offenbar tritt diese Kraft etwa gleichzeitig mit der Initialphase auf *Ihr Verhältnis zur Wanderungsrichtung der vertikalen Kraftresultante* ist in diesen Arbeiten nicht beschrieben worden

Die biomechanischen Zusammenhänge der Initialphase sind noch ungeklärt Sie ist früher nicht in diesem Sinne beobachtet worden Verschiedene Deutungen dieses Phänomenes sind denkbar

1) Beim Aufsetzen des Schuhes auf die Unterlage während eines Schrittes besteht anfänglich ein etwa 20—30 gradiger Winkel zwischen Schuh und Unterlage Der Schwerpunkt der Körpermasse befindet sich dorsal vom Fuss Unmittelbar nach dem ersten Kontakt des Absatzes mit der Unterlage bewegt sich die Spitze des Schuhes zur Unterlage bis die Sohle ganz aufliegt. Diese Winkelbewegung nimmt den Untersuchungen von


148/6
141/10
Y
X
R
L
1mm
SCHRITT I
SCHRITT II

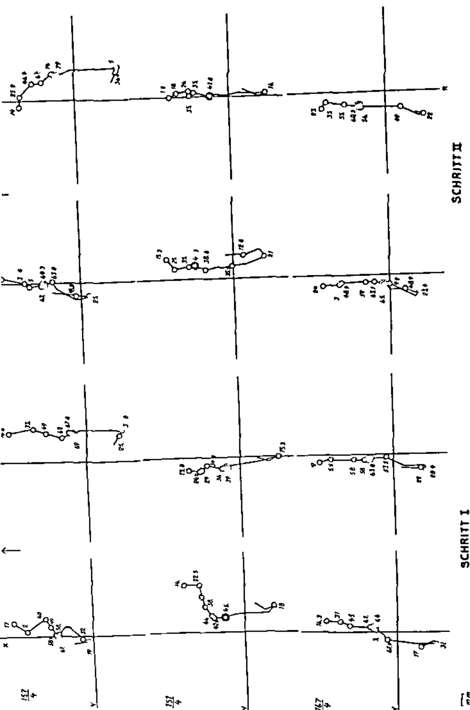


Abb 13 Fersenbelastungsdiagramme (Fbd) von 5 Versuchspersonen bei habituellem Gang in 4 km/h auf der rollenden Gehbahn mit zwei Diagrammen je Fuss von zwei aufeinander folgenden Schritten
(L=Links R=Rechts ↑ =Gangrichtung)

Karpovich und Wilklow entsprechend bei habituellem Gang in etwa 4 km/h c a 6/100 Sekunde in Anspruch Wahrend dieser nach unten gerichteten Winkelbewegung entfernt sich die Unterstutzungsflache des Fusses vom Schwerpunkt des Korpers, der sich dorsal von ihr befindet, d h die Unterstutzungsflache bewegt sich relativ nach vorn Dies bedeutet dass der Schwerpunkt des Korpers nach vollzogener Winkelanderung sich weiter dorsal von der Unterstutzungsflache befindet als beim ersten Aufsetzen des Absatzes Mit anderen Worten die Korpermasse wird nicht mit der gleichen Geschwindigkeit nach vorne geführt mit welcher die Senkung der Fusspitze auf die Unterlage erfolgt (Ware dies der Fall so wurde der Angriffspunkt der Kraftresultante wahrend dieser Phase unverandert bleiben) Wenn eine Winkelanderung zwischen Schwerpunkt der Korpermasse und Mittelpunkt der Messplatte im Absatz in dorsaler Richtung entsteht kann der Angriffsspunkt der Kraftresultante sich in dorsaler Richtung bewegt haben Sobald die Schuhspitze die Unterlage erreicht hat nahert sich hingegen der Schwerpunkt der Korpermasse der Unterstutzungsflache des Fusses welches ein Vorwartswandern des Angriffspunktes der Kraftresultante zur Folge hat Der Zeitablauf der Initialphase hat etwa die gleiche Lange wie die der Senkung der Fusspitze zur Unterlage nach dem ersten Fersenkontakt

(ii) Andererseits konnte man sich in Übereinstimmung mit den von den oben genannten Untersuchern beobachteten horizontalen Kraften eine propulsive Aktion des Fusses unmittelbar nach dem Aufsetzen der Ferse denken Wahrend einer solchen initialen propulsiven Phase konnte ein dorsales Gleiten der Ferse auf der Messplatte im Schuh mit einer entsprechenden Lageanderung des Angriffspunktes der Kraftresultante zur Folge entstehen

Die Klarung dieser kausalen Zusammenhange wird in einer spateren Arbeit versucht werden

Nach der Initialphase stieg die Belastung zu ihrem Maximum an Die Gleichformigkeit dieser Steigerung wurde oft durch eine Unregelmassigkeit unterbrochen wie sie auch Carlsoo Harper und Mitarbeiter und Holden und Muncey gesehen haben (Abb 3) Die Ursache dieser Sonderheit ist bisher noch ungeklart Wahrscheinlich hangt diese Unregelmassigkeit damit zusammen dass beim Aufsetzen der Ferse das Knie und Huftgelenk anfanglich eine geringe Beugungsbewegung ausfuhren die im Sinne einer Verringerung der Belastungskraft wirkt Der Anstieg der Belastungskraft erfahrt eine kurze Unterbrechung um dann nach mehr oder weniger vollstandiger Streckung des Beines wieder fortzusetzen

Der Übergang von der dorsal gerichteten Initialphase zu dem ventral gerichteten Verlauf wird hier im Weiteren als Wendepunkt und der

Teil des Verlaufes vom Wendepunkt bis zur maximalen Belastung als Belastungsphase bezeichnet Nach der maximalen Belastung hier als Maxpunkt bezeichnet folgt die Abwicklungsphase während der die Belastung mehr und mehr auf die vorderen Stutzpunkte des Fusses verlagert wird Die Fbd wurde demnach eingeteilt in (Abb 12)

Initialphase
Wendepunkt
Belastungsphase
Maxpunkt
Abwicklungsphase

Wie aus den Fbd ersichtlich ist der Verlauf der Kurven recht kompliziert und kann nicht ohne Weiteres statistisch bearbeitet werden

Es galt nun eine Auswahl von einem oder mehreren Massen zu treffen die eine vereinfachte aber relevante Beschreibung der Kurven ermöglichen wurde Bei einer solchen Auswahl konnte man nach zwei verschiedenen Prinzipien verfahren

i) Die beschreibenden Masse werden so gewählt dass sie sich so deutlich wie möglich an das biomechanische Geschehen angliedern

ii) Die beschreibenden Masse werden so gewahlt dass sie den Kriterien einer praktischen Anwendungsmoglichkeit entsprechen Wenn man z B ein sog Normalmaterial und ein pathologisches Material zu untersuchen hat, konnte man solche Masse zu finden versuchen die die beiden Materiale am deutlichsten unterscheiden

Da das vorliegende Versuchsmaterial nur aus einem Normalmaterial besteht entfallt die zweite Alternative (ii)

Das Interesse richtete sich hauptsachlich auf die Belastungsphase Am Schluss dieser Phase erreichte die Kraftresultante ihre Maximum Es wurde angenommen dass eine eventuelle supinatorische oder pronatorische Belastungstendenz der Ferse in ihr am deutlichsten zum Ausdruck kommen wurde Diese Annahme grundete sich auf die Vorstellung dass wahrend der maximalen gegen die Messplatte gerichteten Kraft die für die Stabilisierung der Fersenstellung wichtigen anatomischen Strukturen ihre starkste Beanspruchung erfahren würden d h dass ihre eventuelle Nachgiebigkeit dabei in Erscheinung treten wurde

Von allen Möglichkeiten einer Beschreibung der Belastungskurve fiel die Wahl auf folgende definierbare Data

1 *Die Lage des Angriffspunktes der Kraftresultante zum Zeitpunkt ihres Maximums (Maxpunkt) im Verhaltnis zur X Achse* Der seitliche mediale oder laterale Abstand des Maxpunktes von der X Achse entsprach

im Prinzip einer supinatorischen oder pronatorischen Belastungstendenz der Ferse Er war durch den y Wert im Augenblick des maximalen z Ausschlages gegeben Dieser seitliche Abstand des Maxpunktes von der X Achse erhalt im Folgenden die Bezeichnung u wobei —u einer medialen und +u einer lateralen Lage entspricht

2 *Die Quantität der Maxpunktbelastung* Sie war durch den maximalen z Ausschlag gegeben Da sie deutlich mit dem totalen Korpergewicht in Zusammenhang steht versuchte man dessen Variationen zu beruck sichtigen in dem man sie in % des Kopergewichtes ausdruckte Dieses Mass wird im Folgenden mit v bezeichnet

3 *Die Verlaufsrichtung der Belastungsphase vom Wendepunkt zum Max punkt im Verhaltnis zur X Koordinate* Die Verlaufsrichtung wurde durch eine gerade Verbindungslinie zwischen Wendepunkt und Max punkt angegeben Der Verlauf der Kurve zwischen diesen Punkten zeigte in den meisten Fbd sowohl mediale als laterale Abweichungen die jedoch im Sinne der Vereinfachung unberucksichtigt blieben Das Verhaltnis zur X Koordinate wurde in Winkelgraden angegeben Eine Verlaufs richtung der Verbindungslinie parallel zur X Koordinate entsprach 0° Ein im Verhaltnis zur X Koordinate medial gerichteter Winkel erhielt negativen und ein lateral gerichteter Winkel positiven Wert Dieser Winkel wird im Folgenden mit w bezeichnet

In der vorliegenden Arbeit beschrankte sich also die statistische Bearbeitung der Fbd auf die folgenden abhangigen Variabeln

u = der seitliche Abstand des Maxpunktes von der X Koordinate in mm

v = die Grosse der Maxpunktbelastung in % des Korpergewichtes

w = der Winkel zwischen Verlaufsrichtung der Be lastungsphase und der X Koordinate in Graden

Wenn man hier nun im Folgenden bei der Darstellung von Messresulta ten eine Deutung der Zusammenhange zwischen den abhangigen Variabeln und dem biologischen Geschehen zu finden versucht entstehen gewisse Schwierigkeiten

Bei der Erorterung die Ferse betreffender klinischer Gesichtspunkte wurden eine Reihe von klinischen Termen verwendet, wie z B die Prona tion und Supination des Fusses und die Valgus bzw Varusstellung der Ferse Das morphologische oder funktionelle Substrat solcher Termen

ist nicht ganz eindeutig definierbar Eine Anzahl von Publikationen (Fick 1911 Hicks 1961 Manter 1941 Wisbrun 1951 Wright und Mitarbeiter 1962 u a) behandelt solche morphologische und funktionelle Probleme Es *sei daran erinnert dass sich die klinische Beurteilung der* Fersenstellung der Versuchspersonen nur auf Beobachtungen äusserer Konturen der Ferse stützt und dass ihre inneren Strukturen mit Hilfe dieser nicht ausreichend beurteilt werden konnten

Der Verfasser benutzt im Folgenden Bezeichnungen wie Varus und Valgusstellung und Supination und Pronation in dem in der klinischen Praxis gebräuchlichen Sinne einer Deutung der ausseren Konturen Es wird hier auch die gewöhnliche Auffassung der Belastungsverhältnisse bei Valgus und Varusstellung der Ferse *mit medialer und lateraler Lage* des Kraftzentrums acceptiert Angenommen wir erhalten bei Serien von Messungen an Versuchspersonen Veranderungen zwischen zwei Experi*menten mit einer Verlagerung des u Wertes in* medialer oder lateraler Richtung Können solche Beobachtungen einfach als eine Änderung der Fersenstellung im Sinne des Valgus oder des Varus gedeutet werden oder bestehen andere Deutungsmöglichkeiten wie z B die eines Gleitens der Ferse auf der Messplatte oder die eines Gleitens des Calcaneus in seinem Fettpolster?

Im augenblicklichen Stand der Untersuchungen können diese Fragen nicht eindeutig beantwortet werden

Wenn *trotzdem im Folgenden bei der Darstellen von den* Resultaten der Messungen im Hinblick auf ein biologisches Geschehen Deutungen versucht werden so geschieht dies mit den genannten prinzipiellen Einschränkungen

KAPITEL VII

Resultate und Kommentare

1 HABITUELLER GANG IN 4 BZW. 8 KM/H AUF DER ROLLENDEN GEHBAHN

Wie bereits dargestellt, bestand das Versuchsmaterial aus Fersenbelastungsdiagrammen (Fbd) von 47 Versuchspersonen. Es wurden bei jedem Gangexperiment mindestens 2 aufeinander folgende Fersenbelastungen (Fb) je Fuss registriert. Die abhängigen Variabeln u, v und w von 2 aufeinander folgenden Fb (Fb I und Fb II) je Fuss, Person und Versuche bildeten das Material für die statistische Bearbeitung.

Um einen Überblick über das Material zu erhalten, wurden Varianzanalysen für die drei abhängigen Variabeln ausgeführt. Das Resultat ist in den Tabellen 3 und 4 ersichtlich. Die Tabellen 5 und 6 zeigen die arithmetischen Mittelwerte für u, v und w von Fb I bzw. Fb II je Fuss für die beiden Gangexperimente.

Variabilitätsursache	Freiheitsgrade	Mittelwert der Abweichungsquadrate u	v	w
Person	46	7 49	261	417
Fersenbelastung	1	0 01	2	24
Fuss	1	10 39	1269	1731
Fuss × Fersenbelastung	1	0 01	1	12
Person × Fuss	46	2 51	87	149
Person × Fersenbelastung	46	0 72	26	94
Person × Fuss × Fersenbelastung	46	0 94	34	87

Tabelle 3 Varianzanalyse Habitueller Gang 4 km/h (47 Versuchspersonen)

Variabilitatsursache	Freiheitsgrade	Mittelwert der Abweichungsquadrate u	v	w
Person	46	8 42	541	139
Fersenbelastung	1	1 30	37	53
Fuss	1	1 69	2294	668
Fuss x Fersenbelastung	1	0 01	1	3
Person x Fuss	46	2 70	83	97
Person x Fersenbelastung	46	0 43	46	27
Person x Fuss x Fersenbelastung	46	0 47	31	29

Tabelle 4 Varianzanalyse Habitueller Gang 8 km/h
(47 Versuchspersonen)

Fuss	Fersenbelastung	Anzahl	$\bar{u}$	$\bar{v}$	$\bar{w}$
Links	I	47	—0 81	67 8	— 8 9
Links	II	47	—0 81	68 1	—10 1
Rechts	I	47	—0 35	62 7	— 3 4
Rechts	II	47	—0 33	62 8	— 3 6

Tabelle 5 Arithmetische Mittelwerte fur u v und w fur den linken und den rechten Fuss und die Fersenbelastung I und II bei habituellem Gang 4 km/h (47 Versuchspersonen)

Fuss	Fersenbelastung	Anzahl	$\bar{u}$	$\bar{v}$	$\bar{w}$
Links	I	47	—0 31	118 9	—5 1
Links	II	47	—0 15	119 9	—3 8
Rechts	*I*	47	—0 13	112 0	—1 1
Rechts	II	47	0 04	112 8	—0 3

Tabelle 6 Arithmetische Mittelwerte fur u v und w fur den linken und den rechten Fuss und die Fersenbelastung *I und II* bei habituellem Gang 8 km/h (47 Versuchspersonen)

Um die folgende Diskussion der Resultate der Varianzanalyse zu erleichtern wird hier eine kurze Beschreibung der Bedeutung der Variabilitätsursachen gegeben Diese Darstellung erfolgt an Hand der Variabel u fur das Experiment mit habituellem Gang in 4 km/h

Variabilitatsursache Person

Fur jede Person wurde ein Mittelwert aus den 4 u Werten von Fb I und Fb II je Fuss gebildet Die Variation zwischen den 47 Mittelwerten wird durch den Mittelwert der Abweichungsquadrate ausgedruckt Dieser Mittelwert betrug 7 49

Variabilitatsursache Fersenbelastung

Aus der Tabelle 5 ist der Mittelwert der Fb I des linken Fusses mit — 0 81 und der des rechten Fusses mit — 0 35 ersichtlich Der Mittelwert dieser beiden Werte ist — 0 58 In entsprechender Weise erhalt man fur die Fb II einen Mittelwert von — 0 57 Die Differenz zwischen diesen beiden Mittelwerten wird durch den Mittelwert der Abweichungsquadrate ausgedruckt Er betrug 0 01

Variabilitatsursache Fuss

Wie aus der Tabelle 5 entnommen werden kann war der Mittelwert fur den linken Fuss $\left(\frac{\text{Fb I} + \text{Fb II}}{2}\right)$ = — 0 81 und der entsprechende Wert fur den rechten Fuss — 0 34 Die Differenz zwischen diesen beiden Mittelwerten durch den Mittelwert der Abweichungsquadrate ausgedrückt betrug 10 39

Variabilitatsursache Fuss x Fersenbelastung

Diese Ursache wird als Wechselwirkung zwischen Fuss und Fersenbelastung bezeichnet und sie erhalt hier die verkürzte Bezeichnung Fuss x Fersenbelastung

Aus der Tabelle ist ersichtlich dass der durchschnittliche Unterschied zwischen Fb I und Fb II fur den linken Fuss 0 00 und fur den rechten Fuss 0 02 betrug Die Differenz zwischen diesen beiden Mittelwerten wird durch den Mittelwert der Abweichungsquadrate ausgedruckt Dieser Wert betrug 0 01

Variabilitatsursache Person x Fuss (Wechselwirkung)

Fur jede Person wurde der Mittelwert fur den linken und den rechten Fuss gebildet $\left(\frac{\text{Fb I} + \text{Fb II}}{2}\right)$ Mit Hilfe dieser Mittelwerte erhielt man 47 Differenzen zwischen linkem und rechtem Fuss eine fur jede Person Die Variabilitat zwischen diesen Differenzen durch den Mittelwert der Abweichungsquadrate ausgedruckt betrug 2 51

Variabilitatsursache Person x Fersenbelastung (Wechselwirkung)

Fur jede Person wurden die Mittelwerte fur Fb I und Fb II $\left(\frac{\text{Fb I links} + \text{Fb I rechts}}{2}\right.$ und $\left.\frac{\text{Fb II links} + \text{Fb II rechts}}{2}\right)$ gebildet Mit Hilfe dieser Mittelwerte liessen sich 47 Differenzen zwischen Fersenbelastung I und II (eine fur jede Person) bilden Die Variabilitat zwischen diesen Differenzen durch den Mittelwert der Abweichungsquadrate ausgedruckt betrug 0 72

Variabilitatsursache Person x Fuss x Fersenbelastung

Dieser Mittelwert der Abwichungsquadrate kann als eine Art von Fehlerterm angesehen werden Er betrug 0 94 Nahere Einzelheiten uber diese statistischen Begriffe konnen aus einschlagiger Literatur entnommen werden (z B W Snedecor Statistical Methods 1950)

Aus den Tabellen 3 und 5 die die Resultate fur die abhängigen Variabeln u v und w bei habituellem Gang in 4 km/h enthalten kann folgendes abgelesen werden

(i) Für alle drei Variabeln findet man dass der *Mittelwert* der Abweichungsquadrate für Person Fuss und Person x Fuss im Verhältnis zu dem fur Person x Fuss x Schritt gross war (signifikant) Man konnte mit anderen Worten sagen dass signifikante Unterschiede zwischen Versuchspersonen und ein signifikanter durchschnittlicher Unterschied zwischen dem linken und dem rechten Fuss hervortraten und dass unter den individuellen Unterschieden zwischen dem linken und dem rechten Fuss signifikante *Unterschiede zwischen Personen in* Erscheinung traten

(ii) Der *Mittelwert der Abweichungsquadrate* für *Fersenbelastung* und Fuss x Fersenbelastung ist im Verhältnis zu dem für Person x Fuss x Fersenbelastung klein (Eine Signifikanzanalyse mit invertierten Werten ergab keine Signifikanz) Man kann also sagen dass kein *durchschnittlicher* Unterschied zwischen Fersenbelastungen und keine Wechselwirkung zwischen Fersenbelastungen und Fuss nachgewiesen werden konnte

Aus den Tabellen 4 und 6 die die Resultate des Experimentes mit habituellem Gang in 8 km/h zusammenfassen kann folgendes abgelesen werden
(i) Variabel u Der Mittelwert der Abweichungsquadrate für Person und Person x Fuss war im Verhältnis zu dem fur Person x Fuss x Fersenbelastung gross (signifikant)

Variabel v und w Der Mittelwert der Abweichungsquadrate für Person und Fuss war im Verhaltnis zu dem für Person x Fuss x Fersenbelastung gross (signifikant)

(ii) Der Mittelwert der Abweichungsquadrate fur Fuss x Fersenbelastung war im Verhaltnis zu dem fur samtliche abhängigen Variabeln klein (invertierte Werte erreichen keine Signifikanz)

Die statistische Beschreibung des Materiales ergibt dass *kein durchschnittlicher* Unterschied zwischen Fersenbelastung I und Fersenbelastung II und auch keine Wechselwirkung zwischen Fersenbelastung und Person nachgewiesen werden konnte Waren solche Unterschiede beobachtet worden hatte dies darauf deuten konnen dass sich der Gang der Versuchspersonen auf der rollenden Gehbahn vor den Messungen nicht stabilisiert hatte

Im Hinblick auf das Resultat der Varianzanalyse ist es das Gegebene in der weiteren Beschreibung Mittelwerte für Fb I und Fb II *je Fuss und* Person für die drei abhängigen Variabeln zu bilden

Zwischen dem linken und dem rechten Fuss konnte ein durchschnittlicher Unterschied und daruber hinaus eine Wechselwirkung zwischen Person x Fuss nachgewiesen werden Auf Grund dieser Verhaltnisse werden in der weiteren Beschreibung der linke und der rechte Fuss getrennt dargestellt Dies ist auch aus (klinischen) biologischen Gesichtspunkten zweckmassig

(Um von der Abhangigkeit der Fusse von einander bei Signifikanzanalysen ungestort zu sein wurden diese fur jeden Fuss getrennt ausgefuhrt)

Diagram 2 zeigt die Verteilung der Versuchspersonen mit Ausgangspunkt von der Variabel u bei habituellem Gang in 4 km/h und in 8 km/h sowie die individuellen Unterschiede zwischen diesen beiden Experimenten (8 km/h minus 4 km/h)

Diagram 3 und 4 zeigen in entsprechender Weise die Verteilungen fur die Variabel v bzw w Die Tabelle 7 zeigt die arithmetischen Mittelwerte und die Standardabweichungen fur die in den Diagrammen 2 3 und 4 ersichtlichen Verteilungen

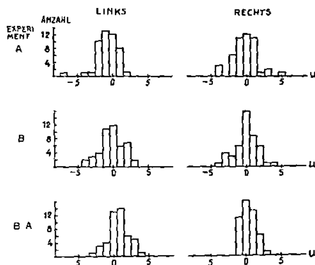


Diagram 2

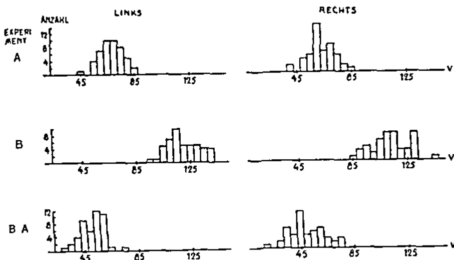


Diagram 3

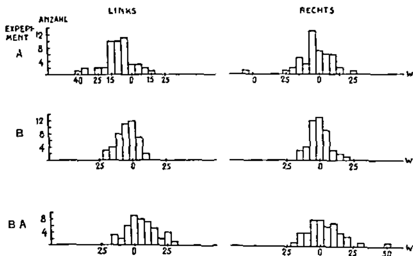


Diagram 4

Diagram 2 3 und 4

Verteilung der Versuchspersonen getrennt fur den linken und den rechten Fuss fur die abhangigen Variabeln u v und w bei habituellem Gang in 4 km/h (A) und 8 km/h (B) sowie die individuellen Unterschiede zwischen den beiden Experimenten (B A)

Zwischen dem linken und dem rechten Fuss konnte ein durchschnittlicher Unterschied und darüber hinaus eine Wechselwirkung zwischen Person x Fuss nachgewiesen werden. Auf Grund dieser Verhältnisse werden in der weiteren Beschreibung der linke und der rechte Fuss getrennt dargestellt. Dies ist auch aus (klinischen) biologischen Gesichtspunkten zweckmässig.

(Um von der Abhängigkeit der Füsse von einander bei Signifikanzanalysen ungestört zu sein, wurden diese für jeden Fuss getrennt ausgeführt.)

Diagram 2 zeigt die Verteilung der Versuchspersonen mit Ausgangspunkt von der Variabel u bei habituellem Gang in 4 km/h und in 8 km/h sowie die individuellen Unterschiede zwischen diesen beiden Experimenten (8 km/h minus 4 km/h).

Diagram 3 und 4 zeigen in entsprechender Weise die Verteilungen für die Variabel v bzw. w. Die Tabelle 7 zeigt die arithmetischen Mittelwerte und die Standardabweichungen für die in den Diagrammen 2, 3 und 4 ersichtlichen Verteilungen.

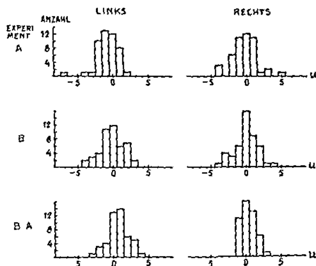


Diagram 2

Variabel u

Wie aus dem Diagram 2 hervorgeht, liegen bei habituellem Gang in 4 km/h nahezu alle u-Werte zwischen +5 und — 5 mm. Die meisten (c. a. 90 %) befinden sich innerhalb einer 4 mm breiten Zone um 0. Diese Variation scheint gering zu sein. Es ist denkbar, dass die nach hinten rollende Gehbahn hierbei einen gewissen Einfluss auf die Versuchspersonen (Vp) ausübte. Die Gehbahn zwang die Vp in einen motorischen Rhythmus hinein und auch dazu, die Balance zu halten. Diese Voraussetzung könnte auf die Variationen innerhalb einer Versuchsgruppe eingewirkt haben. Andererseits muss die Breite der beobachteten Variation mit Vorsicht beurteilt werden, da es noch nicht bekannt ist, wie gross die biologischen Variationen z.B. bei Vergleichen mit pathologischem Material sind.

Bei Erhöhung der Ganggeschwindigkeit auf 8 km/h verlagerten sich die u-Werte durchschnittlich in positiver (=lateraler) Richtung (signifikant für den linken Fuss). Diese Veränderung ist von geringer Grossenordnung. Bei 4 km/h bestand ein durchschnittlicher Unterschied zwischen dem linken und dem rechten Fuss (signifikant). Beim Übergang zu 8 km/h verringerte sich der Unterschied. Beide Beobachtungen könnten so erklärt werden, dass der stärkere Muskeleinsatz infolge der höheren Belastung bei höherer Ganggeschwindigkeit eine Stabilisierung der Ferse zur Folge gehabt haben könnte. Diese Stabilisierung könnte eine Begrenzung der pronatorischen Bewegung der Ferse verursacht haben, welches einer lateralen Verlagerung der Kraftresultante entspricht. Unter Pronation wird hier nicht etwas Pathologisches verstanden, sondern die physiologische Bewegung des Fusses von der leichten Supinationsstellung beim ersten Aufsetzten des Fusses auf die Unterlage an bis zum vollständigen Kontakt der ganzen Unterstützungsfläche des Fusses mit der Unterlage (Steindler 1955, Wisbrun 1951 u. a.).

Variabel v

Aus dem Diagram 3 geht hervor, dass die v-Werte bei habituellem Gang in 4 km/h zwischen c. a. 40 und 85 % lagen (Mittelwert linker Fuss 68 %, rechter Fuss 63 %). Beim Vergleich mit den Resultaten anderer Untersucher (Drillis, Eberhart & Inman, Elftman, Harper und Mitarbeiter u. a.) hatte man etwas höhere Werte erwarten können. Es handelte sich bei den genannten Untersuchungen jedoch um Messungen der totalen vertikalen Kraft aller mit der Unterlage in Berührung befindlichen Stützpunkte des Fusses und nicht um selektive Messungen des Fersenbereiches. Der Maxpunkt der eigenen Messungen fällt etwa mit dem ersten Maximum der oben genannten Messungen zeitlich zusammen (Abb. 1). An diesem Maximum nehmen jedoch bereits vordere Stützpunkte des Fusses

teil welche bei der eigenen Untersuchung nicht registriert werden Ein direkter Vergleich der Resultate ist aus diesen Grunden nicht moglich

Bei Erhohung der Ganggeschwindigkeit auf 8 km/h stiegen die v Werte bedeutend an Der Durchschnittswert fur den linken Fuss war 119 4 % und für den rechten Fuss 112 4 % Diese systematische Belastungszunahme war eine Folge starkerer dynamischer Krafte bei hoherer Ganggeschwindigkeit

Die durchschnittliche Mehrbelastung der linken Ferse in beiden Gang geschwindigkeiten stimmt in gewissem Sinne mit den Resultaten der Unter suchungen von Marsk (1958) überein Er fand eine systematische Mehr belastung des linken Beines bei stehender Arbeit

Variabel u

Aus dem Diagram 4 geht hervor, dass die meisten w Werte bei habi tuellem Gang in 4 km/h (ca 90 %) zwischen — 15° und 15° lagen (durchschnittlich für den linken Fuss —9 6° und fur rechten —3,5°) Beim Übergang zu 8 km/h verringerte sich dieser Winkel durchschnittlich etwas (signifikant fur den linken Fuss) Wie fur die Variabel u konstatierte man einen durchschnittlichen Unterschied zwischen dem linken und dem rechten Fuss der sich bei Erhohung der Ganggeschwindigkeit verringerte

Das Verhalten der Variabel w könnte man ebenso zu erklaren versuchen wie das der Variabel u Eine eventuelle starkere Stabilisierung der Ferse mit einer Begrenzung ihrer pronatorischen Bewegung konnte die Verlaufsrich tung der Belastungsphase so beeinflusst haben dass sie sich weniger medial d h weniger pronatorisch einrichtete

Die Variationen des linken und des rechten Fusses zwischen Versuchs personen die in der Tabelle 7 gezeigt werden konnen in zwei Komponen ten aufgeteilt werden

Zuerst haben wir die Komponente die sich auf Variationen zwischen Fersenbelastungen innerhalb der Person und innerhalb des Fusses zuruck fuhren lasst

Zweitens haben wir die Komponente die sich auf Variationen zwischen den erwarteten Werten der Versuchspersonen bezieht (Der erwartete Wert eines Fusses einer gegebenen Versuchsperson kann als der arithmetische Mittelwert einer grossen Anzahl von Fersenbelastungen unter gleichen Versuchsbedingungen vorgestellt werden)

Durch Ausnutzung der beobachteten Variationen zwischen Fersenbelas tung I und II innerhalb der Person und des Fusses kann man die durch

schnittliche Variation zwischen Fersenbelastung innerhalb Person und Fuss der Versuchsgruppe schätzen Wenn das Resultat dieser Schätzung vom Mass der Variation welches in der Tabelle 7 dargestellt ist subtrahiert wird erhält man ein Mass das eine Schätzung der Variation zwischen den erwarteten Werten der Versuchspersonen ausmacht

Die Tabelle 8 zeigt das Resultat der ausgeführten Berechnung der Werte bei habituellem Gang in 4 km/h

	su		sv		sw	
Variation	links	rechts	links	rechts	links	rechts
Zwischen den erwarteten Werten der Vp	1 4	1 6	7 5	9 3	8 2	10 9
Zwischen Vp (Tabelle 7)	1 5	1 7	8 7	9 8	11 1	12 4

Tabelle 8
Schatzung der Variation (s) zwischen den erwartet n Werten der Vp fur die Variabeln u v und w bei habituellem Gang in 4 km/h

Die in dieser Arbeit dargestellten Gangversuche wurden mit dem Ausgangspunkt von zwei Fersenbelastungen per Fuss und Versuch bearbeitet Hätte man an Stelle dessen eine grössere Anzahl von Fersenbelastungen zur Verfügung gehabt waren die in der Tabelle 7 gezeigten Streuungswerte wahrscheinlich nicht wesentlich geringer gewesen

2 GANG MIT AUSWARTSGESTELLTEN FUSSEN IN 4 KM/H

Eine der Tabelle 3 entsprechende Varianzanalyse der Resultate der Gangversuche mit angestrebter maximaler Auswartsstellung der Fusse wurde ausgefuhrt Das Ergebnis dieser Analyse war analog weshalb die Resultate auch für dieses Experiment mit Hilfe von Mittelwerten fur Fersenbelastung I und II per Person/per Fuss wiedergegeben werden

Diagram 5 gibt die Verteilung der abhängigen Variabel u beim Gang mit auswartsgestellten Füssen in 4 km/h und die individuellen Unterschiede zwischen diesem Gangexperiment und habituellem Gang bei 4 km/h getrennt fur den linken und den rechten Fuss wieder Diagram 6 und 7 zeigen in entsprechender Weise die Verteilung fur die abhangigen Variabeln v bzw w Tabelle 9 zeigt die arithmetischen Mittelwerte und Standardabweichungen für die in den Diagrammen 5 6 und 7 ersichtlichen Verteilungen

Variabel u (Diagram 5) Die u Werte lagen zwischen ca — 4 mm und 4 mm verteilt und der Mittelwert für den linken Fuss war — 0 5 mm und der für den rechten Fuss — 0,3 mm (Tabelle 9) Verglichen mit den Werten bei habituellem Gang in 4 km/h beobachtet man nur einen geringen Unterschied durchschnittlich mit 0,3 mm (nicht signifikant) fur den linken Fuss und keinen Unterschied für den rechten Fuss Die Auswarts stellung des Fusses veranderte die Maxpunktbelastung offenbar durch schnittlich nicht Dies steht in gewissem Sinne im Widerspruch zu den Re sultaten von Karpovich und Wilklow die eine Zunahme des pronatorischen Winkels zwischen Ferse und Unterschenkel bei entsprechenden Experimen ten beobachteten Eine pronatorische Winkeländerung dieser Art muss je doch nicht unbedingt eine pronatorische Änderung der Fersenbelastung zur Folge haben Die genannte Winkeländerung kann sich zwischen Unter schenkel und Ferse abspielen ohne eine Winkelanderung zwischen Ferse und Unterlage zu verursachen Selbst wenn dies der Fall wäre, konnte eine kompensatorische Verlagerung der Körpermasse eine Anderung der Fersen belastung verhindern

Variabel v (Diagram 6) Beim Gang mit auswärtsgestellten Füssen in 4 km/h entstand eine signifikante Erhöhung des arithmetischen Mittelwertes mit 9 2 für den linken und mit 6 7 für den rechten Fuss (Tabelle 9)

Eine Erklärung für dieses Verhältnis könnte man darin zu finden suchen dass der Gang mit volontärer maximaler Auswärtstellung der Füsse die ha bituelle Muskelkoordination und das regelmässige Bewegungsmuster störte zu einer ungelenken Abwickelung des Schrittes und dadurch zu einem här teren Aufsetzen der Ferse führte Die Beobachtung der Versuchspersonen bestätigte diese Annahme Das härtere und eventuelle raschere Aufsetzen nnte eine höhere Belastung erklaren Eine geringe Anzahl von Ver chspersonen gab einen geringeren v Wert bei diesem Experiment im Vergleich mit habituellem Gang bei 4 km/h Es ist denkbar dass in diesen Fällen keine übliche Abwickelung der Belastung von der Ferse zu den vorderen Stützpunkten des Fusses zustandekam sondern dass der ganze Fuss gleichzeitig oder in rascherer Folge die Unterlage erreichte In dieser Weise könnte ein geringerer v Wert der Fersenbelastung entstehen da beim Zeitpunkt der Ablesung bereits ein grösserer Teil der Belastung auf den vorderen Stützpunkten des Fusses ruhte

Variabel w (Diagram 7) Der arithmetische Mittelwert zeigt eine signi fikante Verlagerung zur Minusseite im Vergleich zum habituellen Gang in 4 km h Diese Veränderung betrug — 6 6° für sowohl den linken als den rechten Fuss (Tabelle 9)

Dies bedeutet dass die *Belastungsphase* einen etwas grosseren medialen Winkel bildete Dies war jedoch nicht mit einer durchschnittlichen medialen Verlagerung des u Wertes verbunden Die Verlaufsrichtung der Belastungsphase ist jedoch unter anderem auch von Lageänderungen des Maxpunktes und Wendepunktes parallel zur X Koordinate abhängig Eine Anderung des w Wertes kann demnach ohne Anderung des u Wertes zu stande kommen Die bei Auswärtsstellung der Füsse beobachtete Änderung der Verlaufsrichtung der Belastungsphase in medialer Richtung *konnte man* als die erwartete bezeichnen Man konnte sich vorstellen dass bei auswarts gestelltem Fuss die Belastung von der Aussenseite zur Innenseite des Fusses abgewickelt werden wurde Elftman stellte mit Ausgangspunkt von seiner Untersuchung der Fussbelastung fest dass die Verlaufsrichtung des Kraft zentrums von der Ferse zum Vorfuss eine parallele Einstellung zur Gangrich tung beizubehalten suchte Die eigenen Beobachtungen stimmen damit prin zipiell überein

3 GANG MIT EINWARTSGESTELLTEN FÜSSEN IN 4 KM/H

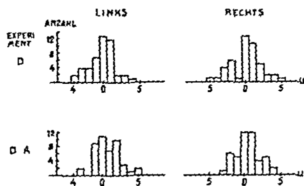
Eine Varianzanalyse entsprechend der in Tabelle 3 wiedergegebenen wurde ausgefuhrt und gab ein analoges Resultat Deshalb wurden auch die Resul tate des Gangexperimentes mit angestrebter maximaler Einwartsstellung der Füsse mit Hilfe von Mittelwerten fur Fersenbelastung I und II per Per son/per Fuss dargestellt

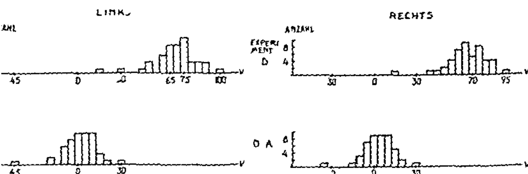
Diagram 8 gibt die Verteilung der abhangigen Variabel u bei Gang mit einwartsgestellten Fussen in 4 km/h und die individuellen Unterschiede zwischen diesem Gangexperiment und habituellem Gang bei 4 km/h separat fur den linken und rechten Fuss wieder Diagram 9 und 10 zeigen in ent sprechender Weise die Verteilungen fur die abhangige Variabel v bzw w In Tabelle 9 finden wir die arithmetischen *Mittelwerte und die Standard* abweichungen der in den Diagrammen 8 9 und 10 ersichtlichen Vertei lungen

Variabel u (Diagram 8)

In Tabelle 9 finden wir, dass die arithmetischen Mittelwerte fur u beim Gang mit einwartsgestellten Fussen eine Veranderung in lateraler Richtung aufweisen fur den linken Fuss mit 0 6 mm und fur den rechten Fuss mit

v





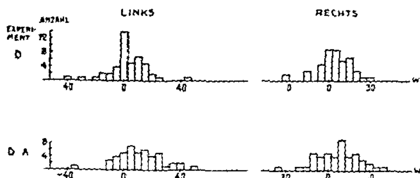


Diagram 8 9 und 10

Verteilung der Versuchspersonen, getrennt fur den linken und rechten Fuss fur die abhangigen Variabeln u v und w bei Gang mit einwartsgestellten *Fussen in 4 km/h* (D) sowie die individuellen Unterschiede zwischen diesem Experiment und dem mit habituellem Gang in 4 km/h (D A)

0 4 mm (Der Unterschied für den linken Fuss erreicht Signifikanzniveau jedoch nicht der fur den rechten Fuss)

Eine solche laterale Verlagerung könnte so gedeutet werden dass die Einwärtsstellung der pronatorischen Bewegung der Ferse entgegenarbeite Eine starke Einwärtsstellung des Fusses kann aus bewegungsphysiologischen Gründen mit einer Supinationshaltung verbunden sein (Karpovich und Wilklow) Es ist denkbar dass diese Supinationshaltung die Ursache der lateralen Lageanderung des Maxpunktes ist

Variabel t (Diagram 9)

Der arithmetische Mittelwert für den rechten Fuss zeigt eine Erhöhung der Belastung im Vergleich zu habituellem Gang in 4 km/h mit 3 8 (signifikant) wahrend der linke Fuss nur eine geringere (nicht signifikante) Anderung mit 1 0 aufweist Aus dem Diagram 8 geht auch hervor dass eine recht grosse Anzahl von Versuchspersonen bei diesem Experiment einen niedrigeren Wert für v erhielt Fur diese Beobachtungen konnte man sich dieselbe Erklarung denken die für die Verhaltnisse der Variabel v bei auswärtsgestellten Fussen (Seite 64) genannt wurde

Variabel u (Diagram 10)

Man beobachtet eine Anderung für w in positiver Richtung durchschnittlich für den linken Fuss mit 11 4° und fur den rechten Fuss mit 7 3° (signifikant fur beide Füsse) siehe Tabelle 9 In Übereinstimmung mit dem was fur das Experiment mit auswartsgestellten Fussen auf Seite 65 gesagt wurde konnte man von der Einwartsstellung erwarten dass sie zu einer Abwickelung der Belastung von der Innenseite zur Aussenseite des Fusses fuhren wurde d h dass sie eine positivere Einrichtung der Belastungsphase zur Folge haben wurde

4 EINE WIEDERHOLUNG DER MESSUNG AN 15 DER 47 VERSUCHSPERSONEN NACH EINEM ZEITINTERWALL VON 2 JAHREN

Die im vorigen Kapitel dargelegten Resultate der Messungen an 47 Versuchspersonen basierten auf einer einmaligen Untersuchung jeder Person die jeweils etwa 15 Minuten in Anspruch nahm Es war von Interesse durch eine Wiederholung der Messungen unter gleichen Versuchsbedingungen festzustellen ob die Variabeln u v und w ein gleichartiges Resultat ergeben wurden (prognostischer Wert der Messungen)

Die Wiederholung der Messungen erfolgte (1964) 2 Jahre nach der ersten Untersuchung (1962) Aus praktischen Grunden wurde die Wieder holung auf solche Versuchspersonen beschrankt die sich nach Abschluss ihrer Ausbildung noch in Stockholm befanden und telefonisch erreichbar waren Von den 16 Erreichbaren kamen 15 Vp im Laufe von 2 Wochen zur Untersuchung

Die klinische Beurteilung der Fersenstellung wurde wiederholt Keine der Versuchspersonen hatte in der Zwischenzeit Krankheiten oder Schaden am Bewegungsapparat erlitten Ungeachtet solcher anamnestischer Angaben be stand die Moglichkeit gewisser Veranderungen der Form und Funktion des Fusses Ein Vergleich mit den Resultaten der Untersuchung von 1962 ergab jedoch keine deutlichen Unterschiede Immerhin kamen geringe Unter schiede in der Beurteilung vor

5 vorher mit ohne Befund beurteilte Versuchspersonen erhielten den Befund angedeutete Varusstellung der Ferse und

1 ebenfalls vorher mit ohne Befund bezeichnete Person erhielt den Befund angedeutete Valgusstellung

Die Unterschiede in der klinischen Beurteilung konnen auf der Unge nauigkeit der subjektiven Untersuchungsmethode beruht haben Andererseits ist es denkbar dass im Verlauf von 2 Jahren Anderungen der Fersenstellung entstanden waren ohne klinische Symptome zu verursachen Die Unter schiede sind jedenfalls gering und die 15 Versuchspersonen konnten wie vorher die Gruppe mit 47 Versuchspersonen als ein Normalmaterial angesehen werden

Die 15 Vp machen eine Art von Stichprobe der ganzen Versuchsgruppe aus Um zu untersuchen ob die 15 sich vom Mittelwert der ganzen Gruppe mehr als erwartet werden konnte wenn sie dem Zufall uberlassend aus gewahlt worden waren unterschieden sind in Tabelle 10 die Resultate der ersten Messungen (1962) an den 15 Vp sowie zum Vergleich die Resultate der ganzen Gruppe von 47 Vp wiedergegeben worden Wie aus der Tabelle hervorgeht besteht kein beachtenswerter Unterschied zwischen den 15 und der ganzen Gruppe

Das Resultat der Wiederholungsmessung an den 15 Vp (1964) geht aus der Tabelle 11 hervor in der die entsprechenden arithmetischen Mittelwerte und dazugehorige Streuungen ersichtlich sind Ein Vergleich zwischen Ta belle 10 und 11 ergibt keine grosseren durchschnittlichen Veranderungen von 1962 bis 1964 Die einzigen Unterschiede die Signifikanzniveau er reichen gelten der Variabel u bei 8 km/h fur den linken Fuss mit einer Lateralverlagerung und der Variabel v bei dem gleichen Experiment mit einer Verringerung der Belastung des linken Fusses

		u				v				w			
		Links		Rechts		Links		Rechts		Links		Rechts	
	Anzahl	$\overline{u}$	s_u	$\overline{u}$	s_u	$\overline{v}$	s_v	$\overline{v}$	s_v	$\overline{w}$	s_w	$\overline{w}$	s_w
Habitueller Gang 4 km/h (A) der ganzen Versuchsgruppe (Tabelle 7 entsprechend)	47	—0 8	1 5	—0 3	1 7	68 0	8 7	62 8	9 8	—9 6	11 1	—3 5	12 4
Habitueller Gang 4 km/h (A) der 15 Versuchspersonen (Stichprobe aus der Versuchsgruppe)	15	—1 0	1 1	—0 4	1 1	69 9	6 7	67 0	10 6	—9 3	8 2	—3 2	11 9
Habitueller Gang 8 km/h (B) der ganzen Versuchsgruppe (Tabelle 7 entsprechend)	47	—0 2	1 7	—0 1	1 7	119 4	11 3	117 4	13 1	—4 5	7 4	—0 7	7 8
Habitueller Gang 8 km/h (B) der 15 Versuchspersonen (*Stichprobe aus der* Versuchsgruppe)	15	—0 4	1 5	0 1	1 1	120 3	12 0	111 1	11 3	—4 1	7 8	—0 9	9 6

Tabelle 10 *Arithmetische Mittelwerte für u v und w* und deren Standardabweichungen (s) von den 1962 ausgeführten Messungen der 15 Versuchspersonen, an denen 1964 eine Wiederholung der Messungen ausgeführt wurde und zum Vergleich entsprechende Werte von 1962 der ganzen Gruppe

		u				v				w			
		Links		Rechts		Links		Rechts		Links		Rechts	
	Anzahl	$\bar{u}$	s_u	$\bar{u}$	s_u	$\bar{v}$	s_v	$\bar{v}$	s_v	$\bar{w}$	s_w	$\bar{w}$	s_w
Habitueller Gang													
4 km/h (A) 1964	15	—0 5	1 4	—0 5	1 3	69 5	7 1	63 3	7 2	—10 4	17 3	—2 4	10 9
Habitueller Gang													
8 km/h (B) 1964	15	0 3	1 3	0 2	1 2	114 7	9 4	108 9	10 5	—2 8*)	5 7	—7 5*)	7 3

Tabelle 11 Arithmetische Mittelwerte fur u v und w und deren Standardabweichungen (s) von der Wiederholung der Messungen an 15 Versuchspersonen 1964 nach einem Zeitintervall von 2 Jahren (* Anzahl 14 An einer der Versuchspersonen konnte der w Wert bei Experiment B nicht festgestellt werden da der Wendepunkt auf Grund unvollstandiger Registrierung der x Kurve nicht identifizierbar war)

Für eine Beschreibung der individuellen Zusammenhänge sind 6 Korrelationsdiagramme abgebildet worden (Diagram 11 12 und 13) Diese zeigen die Abhängigkeit zwischen den Messungen von 1962 und 1964 für die 3 abhängigen Variabeln u v und w bei habituellem Gang in 4 km/h für den linken und rechten Fuss Wie aus den Diagrammen und den Korrelationskoeffizienten (Tabelle 12) hervorgeht enthalten die ausgeführten Messungen einen gewissen prognostischen Wert Tabelle 12 zeigt auch die *Korrelationskoeffizienten für habituellen Gang in 8 km/h welche ein* gleichartiges Resultat aufweisen

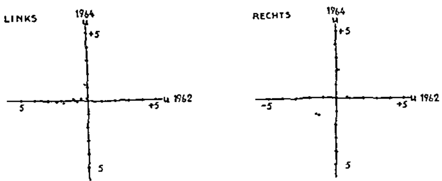


Diagram 11

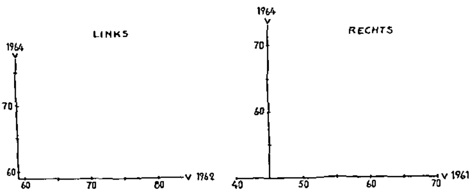
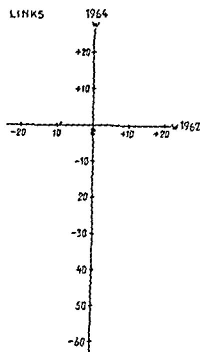


Diagram 12



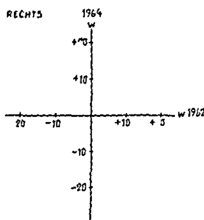


Diagram 13

Diagram 11 12 und 13

Korrelationsdiagramme fur die individuellen Zusammenhange zwischen Messungen von 1962 und 1964 fur die abhangigen Variabeln u v und w bei habituellem Gang in 4 km/h fur den linken und rechten Fuss

		u		v		w	
	Anzahl	Links	Rechts	Links	Rechts	Links	Rechts
Habitueller Gang 4 km/h (A)	15	0 40	0 72	0 71	0 80	0 27	0 35
Habitueller Gang 8 km/h (B)	15	0 72	0 76	0 73	0 59	0 20*)	0 53*)

Tabelle 12 Korrelationskoeffizienten der Werte von 1962 und 1961 der 15 Versuchspersonen (* Anzahl 14 Eine Versuchsperson fehlt siehe Tabelle 11)

Betrachtet man die Variabel w findet man hier den niedrigsten Korrelationskoeffizienten In Anbetracht der Abhängigkeit des w Wertes von sowohl der Lage des Maxpunktes als der des Wendepunktes in Richtung beider Koordinaten kann man sich vorstellen dass er besonders empfindlich ist

5 DIE BEZIEHUNG ZWISCHEN DER VARIABEL U UND DER DER KLINISCHEN BEURTEILUNG ENTSPRECHENDEN FERSENSTELLUNG

Wie bereits genannt betrachtete man die Versuchspersonen im Hinblick auf den Bewegungsapparat als ein sog Normalmaterial Es waren jedoch Befunde angedeuteter Varus und Valgusstellung der Ferse beobachtet worden Diesen konnte nicht direkt pathologische Bedeutung zugemessen werden Man mochte sie eher als anatomische Varianten ansehen

Man fragte sich ob die Variabel u von der Fersenstellung abhangig sein konne Vom klinischen Gesichtspunkt her konnte man sich eine laterale Lage von u bei Varusstellung und eine mediale Lage von u bei Valgusstellung erwarten

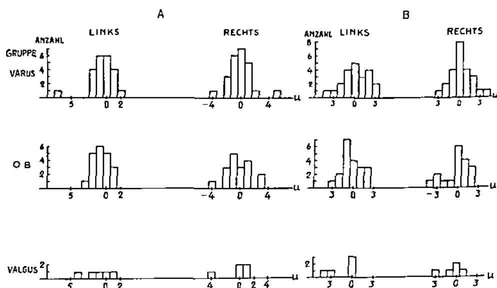
Für eine Untersuchung dieser Verhaltnisse wurden die Fersen der 47 Versuchspersonen mit dem Ausgangspunkt von der klinischen Beurteilung der Fersenstellung in drei Gruppen eingeteilt

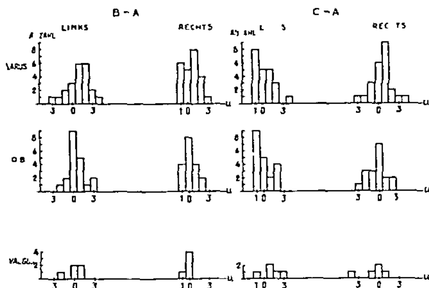
	Links	Rechts	
Varus	22	24	46
Ohne Befund (o B)	20	18	38
Valgus	5	5	10
			94

(Zwei Personen hatten unterschiedliche Befunde zwischen dem linken und dem rechten Fuss)

Die Bezeichnungen Varus , Ohne Befund und Valgus bedeuten also keine Einteilung in klinisch normale und pathologische Falle Es han delt sich um einen Versuch ein sog Normalmaterial mit dem Ausgangs punkt der Tendenzen zu Varus und Valgusstellungen der Ferse einzuteilen

Das Diagram 14 enthalt die Verteilungen der Variabel u bei habituellem Gang in 4 (A) und 8 km/h (B) und deren Differenz (B A) sowie die Differenzen zwischen der Auswartsstellung und habituellem Gang (C A) und der *Einwartsstellung und habituellem Gang* (D A) *bei 4 km/h für den* linken und den rechten Fuss getrennt dargestellt Die diesbezuglichen arith metischen Mittelwerte und Streuungswerte sind aus der Tabelle 13 ersicht lich





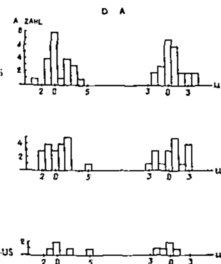


Diagram 14
Verteilung der Versuchspersonen innerhalb der Gruppen (Varus o B Valgus) getrennt fur den linken und den rechten Fuss fur die abhangige Variabel u bei habituellem Gang in 4 km/h (A) 8 km/h (B) die individuellen Unterschiede zwischen B und A (B A) zwischen C und A (Auswartsstellung—habituellem Gang in 4 km/h) und zwischen D und A (Einwartsstellung — habituellem Gang in 4 km/h)

	Varus						O B						Valgus					
	Links			Rechts			Links			Rechts			Links			Rechts		
	Anzahl	u	s_u	Anzahl	u	s_u	Anzahl	u	s_u	Anzahl	u	s_u	Anzahl	u	s_u	Anzahl	ū	s_u
Habitueller Gang 4 km/h (A)	22	—0 7	1 7	24	—0 3	1 7	20	—0 8	1 1	18	—0 3	1 7	5	—1 4	1 5	5	—0 4	1 7
Habitueller Gang 8 km/h (B)	22	0 1	1 8	24	0 2	1 6	20	—0 3	1 3	18	—0 2	1 8	5	—1 4	1 8	5	—0 7	1 6
B—A	22	0 8	1 5	24	0 5	1 1	20	0 5	1 1	18	0 1	1 0	5	0	1 1	5	—0 3	0 4
Auswartsstellung 4 km/h (C) —A	22	0 3	1 2	24	0 4	1 4	20	0 1	1 0	18	—0 5	1 3	5	1 2	1 3	5	—0 5	1 7
Einwartsstellung 4 km/h (D) —A	22	0 6	1 6	24	0 6	1 6	20	0 5	1 8	18	0 4	1 8	5	1 3	1 8	5	—0 4	1 1

Tabelle 13 Arithmetische Mittelwerte der Variabel u und deren Standardabweichungen (s) fur die im Diagram 14 ersichtlichen Verteilungen mit Einteilung der Versuchspersonen in 3 klinische Gruppen

Betrachtet man die arithmetischen Mittelwerte der drei klinischen Gruppen bei habituellem Gang in 4 und 8 km/h und deren Differenz, beschreiben sie ein gewisses Muster das man vom klinischen Gesichtspunkt her erwarten konnte Die Varusgruppe liegt durchschnittlich etwas mehr auf der Plusseite (=lateral) und die Valgusgruppe etwas mehr auf der Minusseite (=medial) (Diese Tendenzen erreichen jedoch nicht Signifikanzniveau) Die geringe Anzahl der Individuen in der Valgusgruppe war für diese Vergleiche ungünstig Bei den Experimenten mit Auswärts und Einwartsstellung in 4 km h treten keine Strukturen hervor die mit klinischen Gesichtspunkten in unmittelbaren Zusammenhang gebracht werden könnten

Im Hinblick auf die geringen Unterschiede zwischen den Befunden der am meisten von einander distanzierten Gruppen Varus und Valgus des vorliegenden Materiales ist es erklarlich dass die erhaltenen Unterschiede in den Messresultaten so gering waren

me fur die Fersenbelastung beim Gehen in Schuhen gewonnen werden die trotz bedeutender Variationen ein zwischen Individuen und zwischen Schritten innerhalb des Individuums vergleichbares Muster beschrieben

Die für eine Charakterisierung der Diagramme gewahlten abhangigen Variabeln *ermoglichten eine gewisse Differenzierung zwischen Versuchs*personen (Kapitel VII 1)

Eine Wiederholung der Messungen an 15 der 47 Versuchspersonen nach einem Zeitinterwall von 2 Jahren (1962—1964) ergab eine nicht geringe Korrelation zwischen den Werten (Kapitel VII 4)

Man beobachtete systematische durchschnittliche Anderungen der Variabeln bei Erhohung der Ganggeschwindigkeit, die mit der grosseren Belastung in Zusammenhang gebracht werden konnten Sowohl bei habituellem Gang in 4 als 8 km/h belastete die Versuchsgruppe durschnittlich die linke Ferse mehr mit etwa 5 % des Korpergewichtes (Kapitel VII 1)

Angestrebte maximale Anderung der Fusstellung (auswarts und einwarts) bei 4 km/h beeinflussten die Verlaufsrichtung der Angriffspunkte der Kraftresultante im Sinne der Beibehaltung einer parallelen Einrichtung zur Gangrichtung (Kapitel VII 2 3)

Da kein pathologisches Material untersucht wurde konnten die differentialdiagnostischen Moglichkeiten der Methode nicht beleuchtet werden Auch die Frage welche abhangigen Variabeln fur eine Differentialdiagnose am besten geeignet gewesen waren hatte es eines pathologischen Materiales bedurft

Es ist die Absicht durch weitere verschiedenartige Experimente naher zu *prufen in welchem Ausmass und mit welchen Mitteln Veranderungen der* Fersenbelastung erzielt werden konnen Hierher gehoren Verschiedenartigkeiten der Schuhkonstruktion und der Beschaffenheit von Fussboden sowie orthopadische Behandlungsmetoden Eine neue Messplatte fur die vorderen Stutzpunktes des Fusses ist in der Absicht sie mit der Messplatte fur die Ferse zu kombinieren hergestellt worden

General Discussion and Summary

The aim of the present work is to report about a method of measuring the weight bearing of the heel *when walking in shoes Furthermore* the intention was to show if such measuring could be of value for a closer study of the weight bearing of the foot

A measuring plate was inserted into the heel of the shoe from the inside This measuring plate is based on the principle of a spring balance The deformation of the spring balance when load is placed on the plate was registered with the help of strain gauges electronically The deformation of the spring balance was in a quantitative relationship to the load With the help of suitable electronic circuits the magnitude and the point of action of the force right angled to the heel plane of the shoe could be read off directly from mirror galvanometers as a function of time

Because of this limitation of the measuring area and the restriction to one force component the construction of the measuring apparatus was simpler compared to other methods of measuring weight bearing on feet The method is relatively uncomplicated and easy to use (chapter III 1 2 3) Sources of error chiefly of a technical kind have been elucidated more closely (chapter III 4)

With regard to the magnitude of the biological variations these errors can be considered to be small

Another sort of errors connected with the orientation of the heel on the measuring plate could not be more closly analysed (chapter III 5) Possible changing of the heel on the measuring plate from step to step and from one experiment to another and different positions between individuals could not be closely checked

The influence from these errors on the possibility of the use of the method depended on the magnitude of the biological variation To get an

opinion on the magnitude of the variations within the individual and between individuals measurings were performed on a group of normal individuals

The group consists of 47 men students from Gymnastiska Centralinstitutet in Stockholm aged around 20

The question is if such a special selection differs from the average of young men without subjective and clinical symptoms The special occupation of the experiment group makes it probable that these individuals were particularly well trained and that for this reason the biological variations were small

The fact that the walking experiments were performed on a tread mill might have had a certain influence on the magnitude of the variations (see page 19) Because of the indirect compulsion to walk and to keep the balance a common factor of influence on all the individuals might be presumed

Experiments with habitual walking at 4 and 8 km/h and such ones with maximum toeing out and toeing in at 4 km/h were performed (chapter V)

From 2 consecutive steps per foot individual and experiment weight bearing diagrams of the heel were made which show the magnitude and the point of action of the force on the measuring plate as a function of time (chapter VI)

With the help of 3 depending variables the weight bearing diagrams were characterized and statistically treated

With regard to the limitation of the experiment group and the above mentioned restrictions one was of opinion that the results of the significance tests should not be particularly emphasized and one preferred a chiefly describing statistical analysis

The working up of the walking experiments took place as mentioned with only 2 steps per foot The estimation of variance of the expected values of the individuals (see page 61) shows that a greater number of steps would probably not have given an essential decrease of the deviations

On the assumption that certain simple relations between the depending variables and the biomechanical occurrences exist the results of the measurings were put in connection with ideas on body kinetics (see page 51)

With the help of the method described in this work diagrams from the weight bearing of the heel when walking in shoes could be produced which in spite of considerable variations were comparable within and between the individuals

The depending variables to characterize the diagrams made it possible to differentiate to a certain degree between individuals (chapter VII 1)

A repetition of the measurings of 15 of the 47 individuals after an interval of 2 years (1962—1964) gave a correlation between the values which is not so small (chapter VII 4)

Systematic average changes of the variables when increasing the walking speed were observed which could be put in relation to the increased load Habitual walking as well at 4 km/h as at 8 km/h showed that the left heel on an average for the group was loaded more with about 5 % of the body weight (chapter VII 1)

Voluntary maximum toeing-out andtoeing in at 4 km/h influenced the path of migration ot the point of action of the force in such a manner that a direction parallel o the walking direction would be kept (chapter VII 2 3)

Because no pathological material was investigated the possibilities of this method for differential diagnostic tests could not be elucidated Also the question which of the depending variables would be most suited for such tests could not be answered without investigating pathological materials

The intention is to prove by means of further experiments of various arts to what extension and by which means the weight bearing of the heel could be influenced Here could be mentioned different sorts of shoe constructions and different kinds of floors as well as orthopaedic methods of treatment A new measuring plate for the fore part of the foot has been constructed with the aim of combining it with the measuring plate for the heel

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KAPITEL IX

Beschreibung der Messapparatur

von Arne Söderholm

ALLGEMEINES

Für die Bestimmung einer Kraft mit gegebener Angriffsrichtung bedarf es der Kenntnis sowohl ihrer Grösse als ihres Angriffspunktes Der Angriffs punkt kann hierbei mit Koordinaten ausgehend von einem gewahlten Re ferenzpunkt, definiert werden

Die Kraft, mit welcher die Ferse den Absatz des Schuhes angreift, kann im Hinblick auf ihre Grösse und in Hinsicht auf ihren Angriffspunkt in Koordinaten in Längs und Seitenrichtung in der Ebene des Absatzes be stimmt werden wobei eine rechtwinklige Richtung der Kraft gegen die Absatzebene vorausgesetzt wird

Für eine Bestimmung dieser Data wird die Absatzebene als eine Platte geformt und mit drei Auflagepunkten in der Peripherie symmetrisch abgestützt Dadurch wird eine stabile und eindeutige Fixierung der Platte erzielt

Durch eine Bestimmung der drei Kraftkomponenten welche die Auflage punkte angreifen können eindeutige mathematische Grossen fur die ge wunschten Data gewonnen werden

Die Kraftkomponenten werden mit drei Blattfedern gemessen welche gegen die Mitte der Platte miteinander verbunden sind und sich von hier *aus gegen die Auflagepunkte strecken (Abb 2) Dadurch dass die Platte* in ihrer Mitte mit den Blattfedern verbunden ist werden diese biegenden Momenten ausgesetzt welche mit der Grosse der Kraftkomponenten der Auflagepunkte proportional sind Die Durchbiegungen der Federn werden mit Dehnungsmesstreifen gemessen welche auf die Federn aufgeklebt sind und die Momente in elektrische Widerstandsanderungen umformen Die Widerstandsanderungen ihrerseits werden in elektrische Spannungsanderun gen umgewandelt welche mit Hilfe geeigneter Bruckenkreise die ge wunschten Data ergeben

$$e_{AD} = e_1 - e_D = e_1 - \tfrac{1}{2}(e_2 + e_3) \qquad (11)$$

Die Spannung e_{AD} entspricht dem Zahler in der Gleichung (8)

In analoger Weise erhalt man eine Spannung die der Gleichung (7) entspricht Die Mittpunkte A und D werden mit einem Potentiometer r_6 verbunden, wobei zwischen dessen Punkt E und der Spannung E/2 eine Spannungsdifferenz e_E entsteht Die Spannung E/2 wird vom Mittpunkt F zwischen den Widerstanden r_7 abgeleitet Fur die Differenz e_{EF} gilt wenn $r_6 \gg r_5$ und $r_7 \approx R$

$$\begin{aligned} e_{EF} &= \beta\,[e_1 - \tfrac{1}{2}(e_2 + e_3)] + \tfrac{1}{2}(e + e_3) \\ &= \beta\, e_1 + \tfrac{1}{2}(1 - \beta)(e + e_3) \end{aligned}$$

Die Zeichen gelten fur das Verhaltnis $e_1 > \tfrac{1}{2}(e_2 + e_3)$ Justiert man β zu

$$\beta = \tfrac{1}{2}(1 - \beta) = \frac{1}{3}$$

erhalt man

$$e_{EF} = \frac{e_1 + e_2 + e_3}{3} \qquad (12)$$

welches der Gleichung (7) entspricht

Die α und β Werte werden bei der Kalibrierung mit bekannter Belas tungsquantitat justiert und man erhalt die Koeffizienten in den Gleichungen (7) (8) und (9) als ein Faktor in den Kalibrierungskonstanten

Die Divisionen in den Gleichungen (8) und (9) elektronisch auszu fuhren ist instrumenttechnisch bedeutend komplizierter und wird als nicht erforderlich angesehen Sie erfolgen rechnerisch

Die erhaltenen Spannungen e_D e_{AD}, e_{EF} durfen wahrend ihrer Messung nicht die Bruckenkreise beeinflussen Deshalb werden die Brucken kreise mit einer Tragerfrequenz von einem Oscillator (c a 1000 Hz) ge speist Die von den Bruckenkreisen erhaltenen Spannungen werden als ent sprechende Wechselspannungen verstarkt und phasenkritisch moduliert d h richtungsgerecht gleichgerichtet Je nach der Richtung der mechanischen Beanspruchung der Messplatte ergibt sich somit ein positiver oder negativer Ausschlag fur die Messwertanzeige Die erhaltenen Spannungen werden mit Spiegelgalvanometern registriert Die Ausschlage der Spiegelgalvanometer z y und x wurden bereits definiert (Seite 18)

Die dynamischen Eigenschaften der Messplatte

Da die Platte federt wenn sie einer Kraft ausgesetzt wird ist ihre Moglich keit begrenzt variierende Krafte wiederzugeben Zuerst seien die Faktoren hervorgehoben die die dynamischen Eigenschaften der Platte bestimmen

Hierzu werden die drei Blattfedern vereinfacht als *eine* Feder gedacht und mit einer Federkonstante dargestellt

$$C_1 = \frac{Q}{\delta_1}$$

wobei δ_1 die der Belastung Q entsprechende Federung oder Deformierung ist Weiter wird angenommen dass die Platte ein Gewicht Q_1 hat

Die die Platte angreifende Kraft der Ferse ruhrt von der Retardation eines gewissen Teiles der Korpermasse her Q_2 welche via der Skelett und Weichteile vermittelt wird Diese Skelett und Weichteile erfahren eine Zusammenpressung oder Deformation δ Die Federkonstante des Korpers kann deshalb analog aufgestellt werden

$$C = \frac{Q}{\delta_2}$$

Dieses System (Korperteile und Messplatte) erhalt die in Abb 18 gezeigte Zusammensetzung Wenn Q die Platte via der Feder C (=Korperteile) angreift werden sowohl diese Feder deformiert als auch die Blattfedern C_1 und die Kraft welche die Platte angreift ist

$$Z = C \quad \delta$$

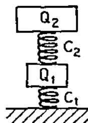


Abb 18 Zusammenstellung der Konstanten die die dynamischen Eigenschaften der Messapparatur bestimmen

Wenn $\delta \gg \delta_1$ wird der Angriff der Kraft Z trots einer Anderung in der Lage der Platte mit δ_1 unverandert sein

Das dynamische System kann unter diesen Voraussetzungen schematisch wie in Abb 19 a wiedergegeben werden Das bedeutet dass das Gewicht der Platte Q_1 und die Blattfedern C_1 ein Schwingungssystem mit einem Freiheitsgrad bilden welches von der störenden Kraft Z angegriffen wird

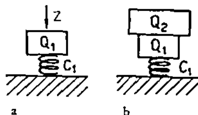


Abb 19 Aktuelle Konstanten a Die Federung des Korpers ist im Verhaltnis *zur Messplatte gross b Die Federung* des Korpers ist im Verhaltnis zur Messplatte gering

Wenn an Stelle dessen ein Gewicht Q die Platte direkt angreift d h $\delta \ll \delta_1$ so besteht das System aus $Q + Q_1$ und der Feder C_1 (Abb 19 b) Das erst genannte System (19 a) kann mathematisch exakt fur verschiedene Variationen von Z behandelt werden wahrend das andere System (19 b) besonders fur stossformig angreifendes Gewicht schwer zu analysieren ist Hierbei sind die dynamischen Eigenschaften prinzipiell schlechter als in dem erstgenannten System Es ist deshalb wichtig die Federung der Platte im Vergleich zur Federung der Korperteile so gering als moglich zu halten, um gute dynamische Eigenschaften zu erzielen

Die dynamischen Eigenschaften in einem System Abb 19 a entsprechend pflegen so untersucht zu werden dass eine storende Kraft gezwungen wird, harmonisch (sinusformig) zu variieren Es gilt zu zeigen dass auch die Deformation in C_1 harmonisch variiert Eine plotzlich angesetzte und danach konstante Kraft (Z_0) zeigt hier jedoch das zeitliche Verhaltnis der Deformation von C_1 besser Dies kann wie folgt ausgedruckt werden (Timoshenko 1932)

$$\delta = \frac{Z_0}{C_1} \left(1 - \cos \sqrt{\frac{g\, C_1}{Q_1}}\; t_1\right)$$

zu dem Zeitpunkt t_1 wenn g die Gravitationskonstante ist In Abb 20 ist dieses Verhalten wiedergegeben Hieraus geht hervor dass δ harmonisch mit einer Amplitude schwingt die doppelt so gross ist wie die der statischen Kraft entsprechenden Besteht eine gewisse Friktion im System (welches unter praktischen Verhaltnissen immer der Fall ist) so ebben die Schwingungen aus und der statische Wert tritt in Erscheinung

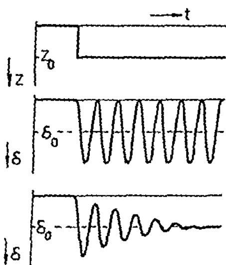


Abb 20 Dynamischer Verlauf der gemessenen Federung bei einer plotzlich aufgelegten und danach konstanten Kraft (Z_0)

Um die Frequenzen der Schwingungen bestimmen zu können müssen Q_1 und C_1 bestimmt werden Im vorliegenden Fall ist $Q_1 \approx 0\,1$ kg bzw $C_1 \approx 150 \quad 10^3$ kg/m welches eine Frequenz von etwa 600 Hz ergibt Für die in der vorliegenden Arbeit gemessenen Verlaufe ist diese Grössenordnung von hinreichender Sicherheit

Referenz Timoshenko S Schwingungsprobleme der Technik J Springer Berlin 1932

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PER EDWARDS

Fracture of the Shaft of the Tibia: 492 Consecutive Cases in Adults

IMPORTANCE OF SOFT TISSUE INJURY

Acta Ort'
Supplementum
Munksgaard C

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM NO 76

From the Orthopaedic Research Laboratories (Head Goran C. H Bauer M D)
of the Orthopaedic Department (Head Sophus von Rosen M D)
University of Lund Malmo General Hospital Malmo Sweden

Fracture of the Shaft of the Tibia
492 Consecutive Cases in Adults

IMPORTANCE OF SOFT TISSUE INJURY

BY PER EDWARDS

MUNKSGAARD COPENHAGEN 1965

PRINTED IN SWEDEN BY
BERLINGSKA BOKTRYCKERIET
LUND 1965

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FIGURES

TABLES

I Introduction

During the period 1841 through 1861 150 patients with open fractures of the lower leg were treated at Guy s Hospital in London Forty nine of these patients died from infection (Bruns p 399) These results were typical for the era preceding the introduction of antiseptic and aseptic management of open wounds In 1882 Bruns (p 398) reported on a series of 126 open fractures of the lower leg with a mortality rate of 7 per cent due to in fection These results from the 19th century indicate the trend over the last one hundred years in the management of fractures of the shaft of the tibia increased efficiency due to prevention and treatment of infection

Today the results of treatment of this fracture are recorded in terms of morbidity rather than mortality Expressed in such terms present day techniques for treatment of fracture of the shaft of the tibia are still far from satisfactory In a series of 3544 such fractures collected from the [illegible] decades gun shot fractures excluded the rate of osteomyelitis was [illegible] (Table 24)

In an earlier investigation of fracture of the shaft of the tibia [illegible] institution (Bauer Edwards and Widmark 1962) it was found [illegible] incidence of infection and poor end results was directly [illegible] etiology of the fractures the results were uniformly good in [illegible] by moderate indirect violence and were relatively poor in [illegible] by severe direct violence These results were interpreted [illegible] prognosis in fractures of the shaft of the tibia was [illegible] severity of soft tissue damage than to the bone injury

This hypothesis was tested in a series of exp[illegible] shaft of the tibia in dogs (Edwards 1965) It [illegible] healing was delayed in those fractures which had a [illegible] over the fracture

Therefore in a series of fractures of the shaft of [illegible] was given to the management of the skin injury [illegible] potentially injured skin was avoided, and primary [illegible] was done with skin grafts when necessary In the [illegible]

here the findings in this *Prospective Series* of fractures are compared with the findings in an earlier consecutive *Control Series*. The results of this comparison are described in three etiologically different types of fracture

II Material and Methods

The material comprised 492 fractures of the shaft of the tibia in 483 adult patients treated in the Orthopaedic Department of the University of Lund at the General Hospital in Malmö (Malmo Allmanna Sjukhus) during the years 1949 through 1963 During the period of this investigation all fracture cases requiring hospital admission in the 225 000 population of Malmo were referred for treatment to the Orthopaedic Department The records of the Orthopaedic Department thus reveal all fractures of the shaft of the tibia diagnosed in Malmo during this period The reader is referred to Alffram (1964) for further definition of the population at risk in this community Some of the cases in this material were studied with isotope techniques by Wendeberg (1961) and by radiometric bone density techniques by Nilsson (1965) All of the 173 fractures described by Bauer Edwards and Widmark (1962) are included in this material *All data pertinent to this investigation are presented in code form in Section IX, A*

A DEFINITION OF PROBANDS

The purpose of this investigation was to assess the value of methods of treatment of fractures of the shaft of the tibia in adults by comparison of associated complications Healing Time and Final Status in a *Prospective* Series with those in a *Control* Series The lower age limit for this study was set at 16 years as done by Ellis (1956) and Bergentz and Thureborn (1957) The limit of the tibial shaft was set proximally at the *tibial tuberosity* and distally at a point *three centimeters above the ankle joint line*

Six groups of patients failed to qualify as probands because they received (a) primary or (b) final treatment elsewhere (c) had serious concomitant disease (d) had multiple injuries of such severity that significant data could not be obtained (e and f) had fractures through obviously pathological bone or (g) died before completion of treatment (Table 1) For epidemiologic reasons all available data concerning those of the above who were residents of Malmo are shown in Section IX B

TABLE 1 Patients with fractures of the shaft of the tibia who did not qualify as Probands

	Control Series	Prospective Series
a Fractures which received primary treatment at another hospital	38	11
b Fractures which received end or final treatment at another hospital	19	2
c Fractures in patients with serious disease or deformities	10	2
d Fractures in patients with such serious other injury that significant data concerning the tibial fracture could not be obtained	2	0
e Fractures through bone grafts or refractures	4	0
f Fractures in Paget s disease	0	1
g Fractures in patients who died a short time after the accident	8	2

Ten patients treated for fracture of the shaft of the tibia in Malmo during the period of this investigation (1949 through 1963) died before completion of treatment Five of them had severe *multiple injuries* and died from *fat embolism* within three days of injury (3 patients), *brain injury* (1 patient) and *myocardial infarction* (1 patient) Five patients without multiple injuries died from verified *myocardial infarction* (1 patient) *suicide* (1 patient), and *pulmonary embolism* 3 4 weeks after injury (3 patients) For reasons stated above none of these patients qualified as pro

The age and sex distribution of the probands is shown in Tables 3 and 4

1 *Control Series*

The Control Series contained 305 probands residents of the city of Malmo, with 311 fractures sustained during the period 1949 through 1960

2 *Prospective Series*

The Prospective Series contained 178 probands from the Southern region of Sweden with 181 fractures sustained during the period 1961 through 1963 Forty six of these probands with 47 fractures were not residents of Malmö

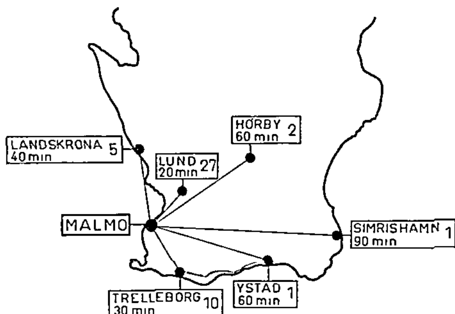


FIGURE 1 Map of Southern region of Sweden showing driving time and number of probands referred to Malmo from other hospitals

3 *Comparison Between Control and Prospective Series*

There was no appreciable difference in the age and sex distribution of probands in the two series The two series differed in one respect by agreement with the chiefs of surgery at five hospitals in the Southern region of Sweden (Fig 1) patients with fracture of the shaft of the tibia were immediately conveyed to the Malmo Orthopaedic Department for treatment regardless of whether or not they were residents of Malmö This agreement was reached for two reasons (a) to increase the number of probands and (b) to test the practical consequences of declaring a specific type of fracture an emergency requiring centralized treatment in the same manner that is accepted for burn injuries

B STATISTICAL METHODS

Standard statistical methods have been used Comparisons subjected to statistical analysis have been indicated in the text as follows

***	$P<0\ 001$
**	$0\ 001<P<0\ 01$
*	$0\ 01<P<0\ 05$
—	$P>0\ 05$

Percentage values shown in the text or in tables are always based on numbers greater than 100

C CLASSIFICATION OF FRACTURES

The material was classified according to (1) anatomic and (2) etiologic parameters

1 *Anatomic Parameters*

The anatomic classification was made in regard to (a) bone injury and (b) soft tissue injury, to distinguish factors which might influence the choice of method of treatment of fractures of the shaft of the tibia

a Bone Injury

Classification of the bone injury was made on the basis of initial radio graphs read by the author Fractures were classified according to (i) *loca tion* (ii) *pattern* and (iii) *displacement*

(i) The *location of fracture* was defined conventionally as being the *upper mid* or *lower* third of the tibia

(ii) The *pattern of fracture* was defined to distinguish between transverse and longitudinal fractures Within the former a distinction was then made between comminuted and not comminuted fractures

α Transverse fractures all fractures in which the fracture line formed an angle of 45 to 90 degrees with the long axis of the shaft and all com minuted fractures i e those with one or more intermediate fragments in volving at least half of the bone diameter By definition double fractures were thus included in this group

β Longitudinal fractures all other fractures i e fractures which have been called long spiral fractures or long oblique fractures

(iii) *Displacement of fracture* was defined in essential agreement with the criteria of Jackson and McNab (1959) and Adler et al (1962)

No displacement fractures without displacement except for angulation in relation to the long axis of the tibia of less than 15 degrees

Moderate displacement fractures with transverse displacement where regardless of angular displacement the contact between the major fragments was at least ½ of the diameter of the shaft or where the shortening was 1 cm or less

Marked displacement all other fractures

b Soft Tissue Injury

The conventional distinction made between *closed* and *open* fracture has been amplified by consideration of the *size of the wound* in essential agreement with the recommendations of Freeman and Jarves (1958) (Table 2) In the Control Series these measurements were invariably found in the case records and in the Prospective Series these measurements were made by the author The size of the wound was defined as

insignificant — (about one centimeter or less)
small — (about 2 to 5 centimeters)
large — (about 6 to 10 centimeters)
major — (more than 10 centimeters or gross defect)

The insignificant and small wounds would roughly correspond to Ellis (1956) minor compound injuries and the large and major wounds to his major compound injuries

No attempt was made to classify injury to muscle or other subcutaneous soft tissues except nerve or major arterial lesions Such lesions were found in only one case

c Contamination of Fracture

The presence or absence of gross contamination in transverse fractures was expressed with relation to the size of the wound and the exposure of the fracture in the wound (Table 2) Primary cultures of micro-organisms were not made

In the entire material the incidence of exposure of the fracture in the wound was higher *** among fractures with wounds larger than 6 cm (37 of 47) than among fractures with wounds less than 6 cm (14 of 71)

There was no difference between the Control and the Prospective Series as regards incidence of exposure of the fractures in the wound or of gross contamination of the open fractures

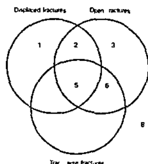


FIGURE 2 Diagrammatic representation of fractures of the tibial shaft classified according to skin injury displacement and type of bone injury

TABLE 2 Relation between the size of wound exposure of fracture and gross contamination in transverse fractures

Control Series					Fracture exposed in wound	Prospective Series				
	The size of wound (cm)					The size of wound (cm)				
Total	< 1	2—5	6—10	> 10		< 1	2—5	6—10	> 10	Total
27(5)	2	8	10(2)	7(3)	+	—	4(1)	9	11(3)	24(4)
44(1)	20	19(1)	4	1	—	8	10	5	—	23
71(6)	22	27(1)	14(2)	8(3)	Total	8	14(1)	14	11(3)	47(4)

Figures in brackets represent number of fractures grossly contaminated with foreign material

TABLE 3 Anatomic classification of fractures of the shaft of the tibia

Anatomic Classification	Venn Diagram Area	Numbers of Fractures Control	Prosp	Total
Displaced Longitudinal Closed	1	118(51)	47(20)	165(71)
Displaced Longitudinal Open	2	7(3)	5(2)	12(5)
Undisplaced Longitudinal Open	3	—	—	—
Displaced Transverse Closed	4	94(23)	62(9)	156(32)
Displaced Transverse Open	5	71(11)	47(9)	118(20)
Undisplaced Transverse Open	6	4(1)	—	4(1)
Undisplaced Transverse Closed	7	17(1)	11(—)	28(1)
Undisplaced Longitudinal Closed	8	—	9(4)	9(4)
Total		311(90)	181(44)	492(134)

Figures in brackets represent fractures in females

d Correlation of Anatomic Parameters

The correlation between pattern of fracture degree of displacement and soft tissue injury was defined through the use of a Venn diagram (Fig 2) It was found that 439 of 492 fractures (89 %) were distributed be tween three of the eight possible types All fractures which belonged to these three types were displaced One of the three types contained *165 closed longitudinal* fractures and the other two types contained all dis placed transverse fractures divided between *156 closed transverse* and *118 open transverse* fractures About one half of the 53 fractures which did not belong to the three main types were undisplaced closed transverse frac tures (Table 3)

This method of correlating anatomic parameters is similar in principle to the one shown as Table V by Nicoll (1964) However Nicoll excluded fractures that later became infected and distinguished between comminuted and not comminuted fractures rather than between transverse and longi tudinal fractures as done here A formal analysis of the significance of a Venn diagram (Feinstein 1963) as regards diagnosis etiology treatment and prognosis of fractures of the shaft of the tibia will be published by Bauer and Edwards (1966)

2 *Etiologic Parameters*

A fracture occurs when the forces applied to the bone exceed the strength of the bone The etiology of fracture may thus be related to two factors (a) bone strength and (b) the nature of the forces applied

a Bone Strength

Bone strength, unfortunately, cannot be measured directly in vivo How ever, by removal from this investigation of cases with obviously diminished bone strength caused by localized lesions such as Paget s disease some uni formity has been assured More important bone strength tends to decrease with increasing age particularly in women (Bauer, 1960 Alffram 1964) identification of the probands in terms of age and sex therefore provided a rough estimate of this factor

b Nature of Forces

The nature of the forces causing a fracture cannot be measured exactly in individual cases However rough estimates of the *direction* and *mag nitude* of these forces can be made It is well known (Adams 1964) that

the direction of the forces operating can be deduced from the shape of the fracture angular or *direct* forces cause transverse fractures, and torsional or *indirect* forces cause longitudinal fractures (Bruns, 1882) A rough estimate of the magnitude of the forces was provided in this investigation by adoption of definitions used in an earlier study (Bauer, Edwards and Widmark 1962) The guiding principle was to distinguish between (i) trauma, resulting from high energy forces, and (ii) trauma, resulting from low energy forces Forces originating from the human body or the equivalent of such forces have been judged as low in energy On this basis the following definitions emerged

(i) Severe violence (283 fractures) resulting from

α All accidents in which a *motor vehicle* was involved (216 fractures),

β *Falls from a height* of more than three meters (12 fractures),

γ *Blows from very heavy objects* (55 fractures) This group included fractures caused by *crush* injuries

(ii) Moderate violence (209 fractures) resulting from all other types of accidents

α *Falls at ground level* or from *low heights* such as chairs or tables (141 fractures),

β *Sports injuries including soccer football* (34 fractures) and *skating* (7 fractures) There were no ski injuries

γ *Bicycle accidents* (27 fractures) in which a motor vehicle was not involved

3 *Correlation of Anatomic and Etiologic Parameters*

The *degree of violence* was determined in the three main anatomic types of fracture defined above that is, closed longitudinal closed transverse, and open transverse types (Table 4) Severe violence caused 84 % of the transverse type fractures and 14 % of the longitudinal type fractures Out of the former 97 % of the open and 74 % of the closed fractures were caused by severe violence The higher incidence of severe violence in the transverse fractures agreed with the *incidence of comminution* it was 44 % in open fractures 31 % in closed fractures caused by severe violence, and 18 % in closed fractures caused by moderate violence

Cases with *multiple injuries* were similarly distributed between the main anatomic types 70 of the 81 cases were found among those caused by severe violence, the incidence of multiple injuries was 31 % in open transverse fractures 20 % in closed transverse fractures and 9 % in longitudinal fractures In the closed transverse fractures the incidence of multiple in

TABLE 4 Correlation of anatomic and etiologic classification of displaced fractures of the shaft of the tibia

Fracture Type	Violence		Total	Mean age ± SD
	Severe	Moderate		
Closed Longitudinal	23(5)	142(9)	165(14)	46.5 ± 15.0
Closed Transverse	116(29)	40(2)	156(31)	42.8 ± 20.3
Open Transverse	114(36)	4(—)	118(36)	44.1 ± 18.8

Figures in brackets indicate multiple injuries

juries was five times higher in those caused by severe violence than in those caused by moderate violence (Table 4)

Among the transverse fractures the *degree of displacement* was marked rather than moderate in 76 % of the closed and 88 % of the open fractures Also among the closed transverse fractures the degree of displacement correlated with the degree of violence Essentially the same correlation was found in the minor anatomic types For example, whereas 18 of the 28 undisplaced, closed transverse fractures were caused by *severe violence* only 2 of these were comminuted, and the 10 fractures of this type which were caused by *moderate violence* were all soccer football injuries

As noted above the age and sex composition of the population at risk is of etiologic importance in fractures of the shaft of the tibia The correlation between this etiologic factor and the anatomic classification is shown in Table 4 Only 19 % of the transverse fractures occurred in females as compared to 43 % of the longitudinal fractures (Table 3)

It was pointed out above that the pattern of the fracture is generally determined by the direction of the forces which caused the fracture It has been shown in this section that the type of fracture based on the correlation between anatomic parameters is closely correlated with the magnitude of the forces which caused the fracture This correlation between anatomic and etiologic parameters indicates that the anatomic clasification provides a detailed etiologic classification closed, longitudinal fractures were caused predominantly by moderate violence whereas transverse fractures were caused by severe violence This pattern became even more apparent by separation of the transverse types in closed and open fractures, the incidence of fractures caused by severe violence was greater *** in the latter type

The anatomic appearance of fracture of the shaft of the tibia thus provides a record of the etiologic factors involved Therefore the anatomic

TABLE 5 Interval between accident and osteosynthesis

Control Series				Prospective Series		
< 24 hours	1—6 days	> 1 week	Type of Fracture	< 24 hours	1—6 days	> 1 wee
66	19	9	Longitudinal	31	1	—
40	7	9	Transverse closed	31	1	—
24	1	12	Transverse open	30	—	1
130	27	30	Total	92	2	1

classification will be used below in the description of treatment complica tions and Final Status of the fractures

4 *Comparison Between Control and Prospective Series*

In residents of Malmö there was no significant difference between the two series with regard to the distribution of fractures between the main ana tomic types and within these types the distribution of the degree of violence was similar The incidence of displaced transverse fractures was 53 % in the Control and 60 % in the Prospective Series and in these groups the incidence of open fractures was identical In both series the open transverse fractures were almost solely the result of severe violence In the Control Series the incidence of closed transverse fractures caused by severe violence was slightly higher than in the Prospective Series (74 of 94 as compared to 42 of 62 fractures) but this difference was not significant The incidence of multiple injury was 17 % in the Control Series and 21 % in the Pro spective Series

The two series did not differ as regards sex and age distribution of pro bands in the main types of fractures

The two series were thus drawn from the same universe as regards etio logy of the fractures

D TREATMENT OF FRACTURES

1 *Primary Treatment*

The general policy at this hospital has been to institute immediate definitive treatment of fractures of the shaft of the tibia Plaster from toes to groin was used in all 492 fractures preceded by a period of traction in only 18 cases all in the Control Series Internal fixation was used in 290 of 425

TABLE 6 Primary treatment of displaced longitudinal fractures

Initial Displacement	Closed or no Reduction		Closed Reduction and Blind Nailing		Open Reduction and Internal fixation		Open Reduction Without Internal Fixation	
	Control	Prospective	Control	Prospective	Control	Prospective	Control	Prospective
Moderate	9	8	—	—	4	—	1	—
Marked	14(2)	7	—	1	90	31	—	—

Figures in brackets represent fractures treated with traction

TABLE 5 Interval between accident and osteosynthesis

Control Series				Prospective Series		
< 24 hours	1—6 days	> 1 week	Type of Fracture	< 24 hours	1—6 days	> 1 wee
66	19	9	Longitudinal	31	1	—
40	7	9	Transverse clo ed	31	1	—
24	1	12	Transverse open	30	—	1
130	27	30	Total	92	2	1

classification will be used below in the description of treatment complica tions and Final Status of the fractures

4 *Comparison Between Control and Prospective Series*

In residents of Malmö there was no significant difference between the two series with regard to the distribution of fractures between the main ana tomic types and within these types the distribution of the degree of violence was similar The incidence of displaced transverse fractures was 53 % in the Control and 60 % in the Prospective Series and in these groups the incidence of open fractures was identical In both series the open transverse fractures were almost solely the result of severe violence In the Control Series the incidence of closed transverse fractures caused by severe violence was slightly higher than in the Prospective Series (74 of 94 as compared to 42 of 62 fractures) but this difference was not significant The incidence of multiple injury was 17 % in the Control Series and 21 % in the Pro spective Series

The two series did not differ as regards sex and age distribution of pro bands in the main types of fractures

The two series were thus drawn from the same universe as regards etio logy of the fractures

D TREATMENT OF FRACTURES

1 *Primary Treatment*

The general policy at this hospital has been to institute immediate definitive treatment of fractures of the shaft of the tibia Plaster from toes to groin was used in all 192 fractures preceded by a period of traction in only 18 cases, all in the Control Series Internal fixation was used in 290 of 425

TABLE 7 Primary treatment of displaced closed transverse fractures

Initial Displacement	(a)		(b)		(c)		(d)		Total	
	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp
Moderate	15(1)	16	—	—	5	—	1	—	21(1)	16
Marked	22(1)	14	1	23	50	9	—	—	73(1)	46

(a) Closed reduction or no reduction
(b) Closed reduction and blind nailing
(c) Open reduction and internal fixation
(d) Open reduction without internal fixation
Figures in brackets represent fractures treated with traction

TABLE 8 Methods of internal fixation of closed transverse fractures

Comminution of Fracture	(a)		(b)		(c)		(d)		(e)		Total	
	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp
—	38	1	—	24(21)	—	—	—	—	4	—	42	25(21)
+	10	3	2(1)	2(2)	1	2	1	—	—	—	14(1)	7(2)

(a) Plate and/or screws with or without encircling wire
(b) Intramedullary nail alone (figures in brackets represent blind nailings)
(c) Intramedullary nail combined with encircling wire
(d) Encircling wire
(e) Other methods

Table 9 Initial treatment of wound in open transverse fractures in Prospective Series

Size of Wound	(a)	(b)	(c)	(d)	(e)	(f)	(g)	Total
Insignificant	8	—	—	—	—	—	—	8
Small	14	—	—	—	—	—	—	14
Large	11	1	—	1	—	1	—	14
Major	3	1	1	—	4	1	1	11
	36	2	1	1	4	2	1	47

(a) Suture
(b) Bipedicle skin flap and split thickness graft
(c) Unipedicle skin flap and split thickness graft
(d) Split thickness graft
(e) Muscle graft and split thickness graft
(f) Muscle graft and skin closure
(g) Muscle graft and bipedicle skin flap and split thickness graft

By contrast the guiding principle of treatment in the *Prospective Series* was primary closure of the skin with care to avoid tension Drainage was not used Immediate skin transplantation always combined with internal fixation, was performed in 8 of 11 wounds over 10 cm in length in 3 of 14 wounds between 6 and 10 cm in length, it was not done in wounds less than 6 cm long Methods used in the treatment of the wound are shown in Table 9 and will be described in detail by Edwards (1965) Special em phasis was placed on providing a muscle bed for the skin graft

(ii) *Bone injury* In the *Prospective Series* the choice of treatment of the bone injury as well was guided by the necessity to avoid additional damage to the skin (Table 10) In the Control Series 13 fractures were treated by skeletal traction This method was never used in the *Prospective Series* There was no significant difference in the frequency of internal fixation in the two series (37 of 71 in the Control Series and 31 of 47 in the Pro spective Series) In the *Control Series* the Lane plate and/or screw were chosen for internal fixation in 30 of 37 fractures (Table 11) In the *Prospective Series* these methods were replaced by intramedullary nailing with the Rush pin (28/31) In 22 of these fractures the nail was used alone blind in 14 and open in 8 In 6 fractures a nail was used in combination with encircling wire Four of these were double fractures

Table 10 Primary treatment of open transverse fractures

Initial Displacement	(a)		(b)		(c)		(d)		Total	
	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp
Moderate	8(3)	3	—	—	3	—	—	—	11(3)	3
Marked	22(10)	12	1	14	33	17	4	1	60(10)	44

(a) Closed reduction or no reduction
(b) Closed reduction and internal fixation
(c) Open reduction and internal fixation
(d) Open reduction without internal fixation
Figures in brackets represent fractures treated with traction

Table 11 Methods of internal fixation of open transverse fractures

Comminution of Fracture	(a)		(b)		(c)		(d)		(e)		Total	
	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp
—	15	1	1(1)	17(12)	—	—	1	—	4	—	21(1)	18(12)
+	15	1	—	5(2)	—	6	—	1	1	—	16	13(2)

(a) Plate and/or screws with or without encircling wire
(b) Intramedullary nail alone (figures in brackets represent blind nailings)
(c) Intramedullary nail combined with encircling wire
(d) Encircling wire
(e) Other methods

d Primary Complications

Complications considered in this investigation were *necrosis of the skin*, and *osteomyelitis* Data on these complications were derived from the case records (Control Series) or by direct observation (Prospective Series)

(i) *Necrosis of the skin* In this investigation necrosis of the skin was defined as that necrosis of the skin located over the antero medial surface of the tibia *and* over the fracture region A distinction was made between *superficial* necrosis of the skin (no exposure of bone) and *deep* necrosis of the skin (with exposure of bone) The incidence of necrosis of the skin is shown in Table 12

(ii) *Osteomyelitis* Osteomyelitis was defined as *obvious infection with fistula formation This definition made it unlikely that such a complication* could have escaped being recorded in the Control Series Osteomyelitis was graded according to the time required for healing and cessation of drainage *mild* when less than one year, *severe* when more than one year The incidence of osteomyelitis is shown in Table 12

In agreement with Adams (1961) no distinction has been made between osteitis (inflammation of bone) and osteomyelitis (inflammation of bone and bone marrow) In accordance with the British and American usage the term osteomyelitis has been preferred even though the term osteitis is commonly used in Sweden

Comments The incidence of fractures with primary complications was greater *** among open (29/118) than among closed fractures (6/156) There was no difference in the incidence of fractures with primary complications in reduced open fractures treated with as compared without internal fixation (Table 13)

The incidence of primary complications in the Control Series in fractures with wounds more than 6 cm in length was greater ** (12/22) than in those with wounds less than 6 cm in length (9/49) (Table 13)

2 *Secondary Treatment*

Secondary treatment of the *skin injury* was defined as those surgical procedures undertaken *24 hours* or more after injury Secondary treatment of the *bone injury was defined as those surgical procedures undertaken 3 months* or more after injury The indications for secondary treatment are shown in Table 14 and will be described below Five fractures all in the Control Series developed complications following secondary treatment (necrosis of the skin and/or osteomyelitis) In four of these fractures the primary treatment had also been associated with complications

TABLE 12 Incidence of primary complications in displaced transverse *fractures*

	No of Fractures		Severe Osteomyelitis		Slight Osteomyelitis		Deep Necrosis of the Skin		Superficial Necrosis of the Skin	
	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp
Closed	91	62	5	—	1	—	2	—	1	
Open	71	17	10	1	3		9	1	9	5
% of Total			9.1 %	0.9 %	2.4 %	0 %	6.7 %	1.8 %	6.1 %	4.6 %

TABLE 13 Primary complications in reduced open transverse fractures

Fractures treated with internal fixation							Fractures treated without internal fixation					
Total		Wound < 6 cm		Wound > 6 cm			Wound < 6 cm		Wound > 6 cm		Total	
no of fract	no of fract compl	no of fract	no of fract compl	no of fract	no of fract compl	Material	no of fract	no of fract compl	no of fract	no of fract compl	no of fract	no of fract compl
37	12(8)	28	6(5)	9	6(3)	Control	21	3(2)	11	6(3)	31	9(5)
11	6(—)	11	—	18	6(—)	Prospective	8	1(—)	6	1(1)	14	2(1)
48	18(8)	[illegible]	6(5)	27	12(3)	Total	29	[illegible]	19	7(4)	[illegible]	11(6)

Figures in brackets represent fractures with osteomyelitis

a Indications

(i) *Skin injury* Ten fractures in the Control Series and 8 fractures in the Prospective Series were treated because of necrosis of the skin In the *Control Series* 18 operations were performed 2—48 months after injury In most cases transplantation with a cross leg flap or split thickness grafts was used Split thickness grafts were the final treatment in all but 2 fractures In the *Prospective Series* 10 operations were performed 2 10 weeks after injury in all but one, transplantation with split thickness skin grafts was performed Four operations in 2 fractures were done as completion of immediate skin grafting

(ii) *Slow union* Twelve transverse fractures in the Control Series and 18 in the Prospective Series were treated secondarily because of slow union In both series the majority were treated with *bone grafts* alone, or in combination with an *intramedullary nail* Healing was obtained in all but two cases treated with this indication, both in the Control Series

(iii) *Osteomyelitis Thirteen transverse fractures in the Control Series* and one in the Prospective Series were operated secondarily because of osteomyelitis The procedures were *sequestrectomy* and/or *saucerization* The infectious process as well as the fracture healed in all but 5 cases These 5 cases occurred in the Control Series and 3 of these were later treated by *amputation* 1, 2 and 6 years after the initial injury

(iiii) *Ankle joint stiffness* In 2 transverse fractures in the Control Series *Achilles tendon lengthening and posterior capsulotomy* of the ankle were done to correct ankle joint contracture

(v) *Malalignment* Tibial *osteotomy* because of malalignment was done in 2 transverse and 1 longitudinal fracture in the Control Series and in 1 transverse fracture in the Prospective Series

b Osteomyelitis in Relation to Necrosis of the Skin in Transverse Fractures (Table 15)

The incidence of osteomyelitis was higher *** in fractures with necrosis of the skin (16 of 30) than in those without necrosis of the skin (6 of 244)

The incidence of osteomyelitis was higher ** in fractures with deep necrosis of the skin (13 of 16) than in those with superficial necrosis of the skin (3 of 14)

The incidence of severe osteomyelitis was higher *** in fractures with deep necrosis of the skin (12 of 16) than in those with superficial necrosis of the skin (1 of 14)

TABLE 14 Secondary treatment of displaced fractures of the shaft of the tibia

Type of Fractures	Number of Fractures		Indication for Secondary Treatment: Malalignment		Ankle Joint Stiffness		Osteomyelitis		Slow Healing	
	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp	Control	Prosp
Longitudinal	118	47	1	—	—	—	—	—	—	—
Closed Transverse	94	62	—	—	—	—	5	—	5	5
Open Transverse	71	47	2	1	2	—	8	1	7	13

TABLE 15 Osteomyelitis in relation to necrosis of the skin in transverse fractures

Necrosis of the skin	Osteomyelitis: None	Slight	Severe	Total
None	238	1	5	244
Superficial	11	2	1	14
Deep	3	1	12	16
Total	252	4	18	274

E HEALING TIME

1 *Collection of Data*

Healing Time was defined here as the period of time from the accident until full clinical stability of the fracture had been reached Stability was checked each time the plaster was changed Due to the closer personal attention to the fractures in the Prospective Series over estimation of the Healing Time probably occurred to a lesser degree in that series than in the Control Series

2 *Analysis of Data*

For the purpose of comparing the Prospective with the Control Series with regard to Healing Time in the three main fracture types two parameters were defined (a) time for healing of 50 % of the fractures, and (b) time for healing of 95 % of the fractures The former parameter was analyzed because of general convention However, it is insensitive to the occurrence in a group of fractures of a subgroup with extremely long Healing Times Here the 95 % Healing Time is superior, it is sensitive to both of two important modalities in a family of data, average and distribution In studies of fracture healing this latter modality is of supreme importance because the distribution of Healing Times is always skewed, no fracture heals instantaneously and some may never heal The methods used in this analysis of Healing Time are based on graphic probit analysis, and the results of this analysis have been published by Edwards and Nilsson (1965)

3 *Presentation of Data*

Individual Healing Times are shown in Section IX A The 50 % and 95 % Healing Times are shown in Tables 20 and 22

F FINAL STATUS OF FRACTURES

One year or longer after the injury the probands were evaluated to determine the Final Status of the fracture of the shaft of the tibia (Table 16)

1 *Follow up of Probands*

The Final Status could be evaluated in 95 % of the 483 probands of this investigation All probands who had had complications in the form of

TABLE 16 Probands evaluated for Final Status of fractures

Control Series			Prospective Series	
Probands	Fractures		Probands	Fractures
305	311	*Primarily Treated*	178	181
		Follow-up		
14	14	Dead	1	1
9	9	Not available	—	—
282	288	Available for evaluation	177	180
		Final Status		
9	10	Excluded because of other injuries or disabilities	6	7
273	278	Available for classification of final status	171	173

necrosis of the skin osteomyelitis or pseudarthrosis were available for evalution of Final Status

a Control Series

At the time of follow up 1960 1961 14 probands were dead, 9 probands could not be traced and 282 probands with 288 fractures were available for evaluation (Table 16) All probands received and answered a question naire concerning shortening of the fractured leg restriction of motion of ankle or knee joints pain swelling skin ulcers disability pension and ability to return to previous occupation On the basis of these question naires and the case histories 180 fractures were examined by a team of three orthopaedic surgeons 59 of these fractures were examined by the author These 180 fractures included (1) all probands who had answered that they had residual symptoms from the injured extremity (2) all probands whose case histories revealed that when last seen at the hospital they were not completely free from complaint or physical evidence of defective function or malalignment and (3) all patients whose case records suggested that complications had occurred

The case records in the 23 probands who were unavailable for follow up were analyzed for incidence of complications and all other factors except Final Status None of those probands had had necrosis of the skin, osteo myelitis or p eudarthrosis

b Prospective Series

All but 4 of the 178 probands of the Prospective Series were followed con tinuously by the author One of these 4 died before completion of treatment from chronic heart disease, 2 were treated at an institution for alcoholics and 1 had moved to another region The last case was evaluated by another orthopaedic surgeon according to a detailed scheme and the other 2 were evaluated by the author Thus 177 of the 178 probands of the Prospective Series were available for evaluation

2 *Classification of Final Status of Fractures*

The Final Status of fractures was classified as *good fair* or *poor* according to criteria shown in Table 17 The fractures were classified according to the lowest rating obtained in any one of the 8 categories studied

3 *Probands with Multiple Injury*

In the classification of Final Status of fractures consideration was given to the following

a Other Injury to the Same Limb Sustained Simultaneously

In the entire material 37 fractures of the shaft of the tibia were associated with fractures of the ankle (20), foot (3) knee (7), femur (5) femoral neck (2) and fracture of vertebrae with paresis of the legs (1)

Nine fractures in the Control Series and 5 fractures in the Prospective Series were excluded from classification of Final Status because persisting symptoms and signs were such that it was probable they were not related to the fracture of the shaft of the tibia All 14 had symptoms and impaired function related directly to the associated fractures When persisting symptoms or impaired function did not relate directly to the associated fracture the probands were included in the classification of the Final Status

All of the excluded fractures healed without evidence of persisting osteomyelitis Two of these had had complications 1 osteomyelitis in the Control Series and 1 necrosis of the skin in the Prospective Series

TABLE 17 Classification of Final Status of Probands

		Good	Fair	Poor
1	Pain	Little or none	Slight	Severe
2	Work Capacity	Normal	Difficulty or inability to do heavy work	Markedly decreased light seated work only
3	Limp	None	Slight with or after severe exercise	Constant
4	Sports Activity	Normal	Decreased ability	Short walks only
5	Knee Motion	Stable full extension loss of flexion less than 20	Stable full extension flexion to at least 90	Lack of full extension flexion to less than 90
6	Ankle Motion	Less than 10 loss of dorsiflexion less than 20 loss of plantarflexion	Dorsiflexion over 90 less than 30 loss of plantar flexion	Dorsiflexion less than 90 more than 30 loss of plantarflexion
7	Foot Motion	Less than 25 % decrease of pro- and supination	Moderately decreased	Severely decreased
8	Swelling of Lower Leg	Slight only after exercise	Slight	Constant

Poor results also include
1 amputation
2 osteomyelitis with recurrent drainage
3 pseudarthrosis

b Disability or Injury to the Same Limb Occurring Before Evaluation of Final Status

Two probands with fracture of the tibial plateau (1 in each series), and 1 proband (Prospective Series) with diabetic gangrene were excluded because the Final Status could not be evaluated

c Status Prior to the Injury

If records showed that there had been prior disability of the affected limb such disability was considered in the classification of Final Status

In the Control Series 273 probands with 278 fractures and in the Prospective Series 171 probands with 173 fractures were available for evaluation of Final Status

III Results

The results of this investigation are expressed in terms of (A) comparison of the Prospective with the Control Series as regards incidence of complications, Healing Time and Final Status in the three main fracture types, and (B) correlation of the incidence of osteomyelitis with Healing Time and Final Status

A COMPARISON OF PROSPECTIVE SERIES WITH CONTROL SERIES

1 *Longitudinal Fractures*

The Final Status in the 149 longitudinal fractures was 83 % good and 17 % fair with little difference between the Control and the Prospective Series (Table 18) None of the fractures of this type had a poor Final Status Only one complication was observed a fracture with superficial skin necrosis in the Control Series

The Healing Times for both 50 % and 95 % of the fractures were somewhat shorter in the Prospective as compared to the Control Series (Table 19)

2 *Closed Transverse Fractures*

A marked difference between the Control and the Prospective Series was observed as regards incidence of osteomyelitis (Table 12) and Final Status (Table 20) in the closed transverse type of fracture

In the *Control* Series 7 of 94 fractures developed osteomyelitis (6 primary and 1 secondary) In the *Prospective* Series none of 62 fractures developed osteomyelitis

In the entire material the Final Status was good in 75 % fair in 20 % and poor in 5 % None of the 7 fractures with poor Final Status occurred in the Prospective Series

There was no difference between the two Series as regards Healing Time

TABLE 18 Final Status in longitudinal fractures

	Good	Fair	Poor	Total
Control Series	82	22	—	104
Prospective Series	41	4	—	45
Total	123	26	0	149

TABLE 19 Fracture healing time

	Healing time for 50 % of the group (months)		Healing time for 95 % of the group (months)	
Type of Fracture	Control	Prospective	Control	Prospective
Displaced closed longitudinal	2 9	2 2	5 0	3.5
Displaced closed transverse	3 5	3 1	12	9 0
Displaced open transverse	4 8	4 5	20	14

TABLE 20 Final Status in closed transverse fractures

	Good	Fair	Poor	Total
Control	58	22	7	87
Prospective	54	8	—	62
Total	112	30	7	149

(Table 19) for 50 % of the fractures The Healing Time for 95 % of the fractures was shorter in the Prospective as compared to the Control Series

3 *Open Transverse Fractures*

A marked difference between the Control and the Prospective Series was observed as regards incidence of osteomyelitis (Table 12) and Final Status (Table 21) in the *open transverse type of fracture*

In the *Control* Series 14 of 71 fractures developed osteomyelitis (13 primary and 1 secondary) In the *Prospective* Series 1 of 47 fractures developed osteomyelitis

TABLE 21 Final Status in open transverse fractures

	Good	Fair	Poor	Total
Control Series	31	19	14	64
Prospective Series	32	9	1	42
Total	63	28	15	106

TABLE 22 Effect of osteomyelitis on healing time

Type of Fracture	Healing time for 95 % of the group (months)	
	Including Osteomyelitis	*Excluding* Osteomyelitis
Closed transverse fractures (control+prospective series)	10	9
Open, transverse fractures (control+prospective series)	19	14
Open transverse fractures (control series)	20	14
Open transverse fractures (Prospective series)	14	14
Fractures complicated by osteomyelitis (control+prospective series)	34	

In the entire material the end results were good in 59 % fair in 26 % and poor in 15 % Only 1 of the 15 fractures with poor Final Status occurred in the Prospective Series

There was no difference between the two Series as regards Healing Time for 50 % of the fractures (Table 19) The Healing Time for 95 % of the fractures was markedly shorter in the Prospective as compared to the Control Series

4 *Other Fractures*

There were no complications in the 47 fractures which did not belong to the three main fracture types. The Final Status was good in 46 cases and fair in 1 case No comparison between the Control and Prospective Series was made in this small group of heterogenous fractures

TABLE 23 Correlation of osteomyelitis and Final Status in transverse fractures

Final Status	Osteomyelitis	
	Control	Prospective
Good	3	—
Fair	4	—
Poor	13	1

B CORRELATION OF OSTEOMYELITIS WITH HEALING TIME AND FINAL STATUS IN TRANSVERSE FRACTURES

1 *Healing Time*

Table 22 shows the time for healing of 95 % of the transverse fractures with a distinction between those complicated and those not complicated by osteomyelitis The difference between the two Series in Healing Time for 95 % of the fractures was found to be due entirely to the higher incidence of osteomyelitis in the Control Series

2 *Final Status*

All of the 22 fractures with poor Final Status in this investigation occurred in displaced transverse fractures either open or closed treated with open reduction and internal fixation.

a Fractures Complicated by Osteomyelitis (Table 23)

The Final Status was classed as poor because of (a) *amputation* 3 fractures (all in the Control Series) were amputated because of chronic osteomyelitis In 2 of these the fracture had not healed (b) *chronic osteomyelitis* 4 fractures (all in the Control Series) had chronic osteomyelitis with drainage continuing over 4 to 10 years In 3 of these the Final Status was poor also because of marked ankle joint stiffness (c) *other criteria* 7 fractures (6 in the Control Series) were classed as poor according to criteria shown in Table 17 All had severe stiffness of the ankle or foot with severe objective as well as subjective disability In no case was there severe limitation of knee motion in 5 of the 7 cases knee motion was normal

b Fractures Uncomplicated by Osteomyelitis

The Final Status was classed as poor because of (a) *pseudarthrosis* 2 fractures in the Control Series did not heal (b) *other criteria* 6 fractures (all in the Control Series) were classed as poor, 2 because of markedly impaired walking capacity combined with pain, and 4 because of marked stiffness of the ankle joint with both subjective and objective disability

COMMENTS

No fracture was found to have poor Final Status because of decreased knee motion Of 13 fractures which were classed as poor by criteria other than amputation, chronic osteomyelitis or pseudarthrosis, 8 had normal knee motion and 5 had only moderate decrease of knee motion Limitation of ankle and/or foot motion particularly dorsiflexion was the criterion in these cases

IV Discussion

In this investigation two consecutive series of fractures of the shaft of the tibia received treatment which differed in that in the second or Prospective Series particular attention was paid to associated skin lesions with the object of preventing bone *infection A comparison of Final Status in the Con*trol and Prospective Series showed that this object was achieved and that the incidence of fractures with osteomyelitis pseudarthrosis and poor function fell to nearly zero This finding will be discussed below in relation to proposed causes of poor results of treatment of fractures of the shaft of the tibia

A. CAUSES OF POOR RESULTS IN FRACTURES OF THE SHAFT OF THE TIBIA

Three factors tend to interfere with healing of bone, (1) deficient blood supply (2) poor apposition of fracture fragments and (3) infection

1 *Deficient Blood Supply*

a Effect of Fracture Upon Nutrient Artery

Slow or non union of fractures of the shaft of the tibia have been attributed to deficient blood supply through the nutrient artery in Watson Jones textbook *(1957 Fig 29 p 16) for example fractures at the junction of* the lower and middle thirds of the shaft of the tibia are depicted as jeopardizing the blood supply to the lower of the fragments in the same way *as fractures of the femoral neck* or of the carpal scaphoid bone The evidence for this mechanism is largely circumstantial in the past pseudarthrosis of fractures in this area was particularly frequent. However, this observation can be just as easily explained by the fact that most open comminuted fractures of the shaft of the tibia occur in this region In this investigation for example open comminuted fractures affected the lower two-thirds of the shaft 34 times out of 38 Furthermore the incidence of delayed union and non union seems to be evenly distributed over *the tibial shaft* (Ellis 1956 Nicoll 1964) Finally in cases of non union of the shaft of the

tibia studied with tracer techniques, no evidence of deficient blood supply has been found (Wendeberg, 1961) In the investigation reported here the improved results following frequent use of intramedullary nailing cannot be related to blood supply as an important factor

b Loss of Blood Supply to Intermediate Fragments

Poor results in comminuted and double fractures have often been explained as due to poor blood supply of the intermediate bone fragments, especially after periosteal stripping (Compere, 1949) during open reduction Little evidence is available to support this view It is more impressive, perhaps, that non union is often successfully treated with the aid of grafts completely devoid of blood supply This investigation does not prove or disprove the hypothesis discussed here The results suggest, however that it is of limited value as an explanation for *poor* results of fractures of the shaft of the tibia

2 *Poor Apposition of Fracture Fragments*

Whereas fractures may unite even under extremely unfavourable conditions of apposition of the fracture surfaces, there is unanimous agreement that good apposition and stability of any fracture are desirable

Treatment by traction of fracture of the shaft of the tibia may result in slow or non union, not necessarily related to distraction (Watson Jones and Coltart 1944) Nicoll (1964) found that there was a high incidence of delayed union among fractures treated by continuous traction related less to the traction treatment and more to the greater incidence of higher risk fracture types among fractures so treated This suggests that such me chanical factors as the degree of stability at the fracture site may be re latively unimportant as regards the etiology of poor results in the treatment of fracture of the shaft of the tibia

The Lane plate has been felt to maintain separation of fracture frag ments caused by resorption of bone in the process of healing The slotted plate was introduced to permit compression of the fracture ends However, experimental attempts to exert pressure on the fracture ends have been un successful in shortening Healing Time (Reynhold and Key, 1953 1954) and there are no clinical reports that slotted plates have given better results than the Lane plate (Cave 1965)

In this investigation the plate was used in the Control Series with good results in fractures caused by moderate violence and the results became in creasingly poor in proportion to the severity of violence that caused the fracture In tibial osteotomies the Lane or slotted plates have been used

without untoward effect One may conclude, therefore, that poor results following use of the plate are related to the type of fracture rather than to the plate itself

3 *Infection*

The role of infection as a cause of poor results in treatment of fractures in general and of fractures of the shaft of the tibia in particular is well documented Before Lister the mortality rate in open fractures of the shaft of the tibia was about 40 %, immediate amputation was the method of lowering this rate Recognition of bacteria as the cause of infection, and institution of appropriate antiseptic or aseptic precautions reduced the mortality rate to about 5 % (Bruns 1882) In more recent literature the results of treatment of open fractures of the shaft of the tibia under peacetime conditions are measured in terms of morbidity rather than mortality, but infection still rates high as a cause of poor results For example, Campbell (1960) found 15 cases of non union in 100 open fractures of the shaft of the tibia 10 of those associated with infections Nicoll (1964) reported on 22 infected wounds in 144 open fractures with delayed or non union in 13 of these infected cases Hicks (1964) showed that two thirds of amputations for fracture of the shaft of the tibia performed at the Birmingham Accident Hospital were due to infection He pointed out that necrosis of the skin was feared as starting a chain of events that lead to amputation

The correlation between necrosis of the skin and osteomyelitis was particularly striking in the investigation reported here 12 of 18 fractures with severe osteomyelitis had deep necrosis of the skin Three cases were amputated all had infection and 2 had established pseudarthrosis of the fracture

In their clinical analysis of Healing Times for fracture of the shaft of the tibia Urist et al (1954) had difficulties in establishing realistic values for fractures complicated by osteomyelitis because of a high frequency of amputations In this investigation amputation was rarely performed

The disastrous effect of osteomyelitis on healing of fractures of the shaft of the tibia was clearly shown by comparison of the time for healing of 95 % of the fractures it was 14 months in open transverse fractures without osteomyelitis and 34 months in fractures with osteomyelitis (Table 22)

4 *Conclusion*

One may conclude that osteomyelitis still looms large as the leading cause of poor results following treatment of fracture of the shaft of the tibia

B PREVENTION OF INFECTION IN MANAGEMENT OF FRACTURES OF THE SHAFT OF THE TIBIA

1 *Longitudinal Fractures*

The results of this investigation emphasize the well known fact that longitudinal fractures are very rarely open, and if so, the wounds are of little consequence The reason is that these fractures are caused by indirect, moderate violence which probably only rarely results in a crush injury of the skin *Therefore, the management of these fractures carries little or no risk* of necrosis of the skin or subsequent infection In this series of 165 such fractures 76 % of which were treated with internal fixation, usually with screws or occasionally with a plate the results were uniformly good with regard to infection Only 1 fracture with superficial necrosis of the skin was encountered, and this complication did not affect the Final Status of the fracture The uniformly favorable results of internal fixation of this type *of fracture noted in this investigation do not necessarily mean that operation* is the method of choice The results do show, however, that open reduction and internal fixation does not materially increase the risk of infection over that associated with other types of elective surgery

In the Control Series the operative approach to the fracture was always directly through the skin over the antero-medial surface of the tibia In the Prospective Series an approach was chosen which avoided the sub*cutaneous surface of the tibia the osteosynthesis material was always placed* under muscle This difference in approach failed to influence the incidence of complications it was close to zero even in the Control Series By comparison with transverse fractures usually caused by direct severe violence one may conclude that the skin over longitudinal fractures has not been crushed, and that it can therefore tolerate operative incisions

2 *Closed Transverse Fractures*

The literature contains abundant evidence that conservative treatment of this fracture is hardly ever associated with infection (Bohler 1957) and that open reduction and internal fixation of this fracture are associated with a high incidence of infection (Table 24) Indeed with reference to the discussion above it seems probable that the reason the Lane plate has come into disrepute is because mechanically it has been the method of choice in this type of fracture The data from the literature receive support from the findings in this investigation there were no infections among the 67 closed transverse fractures in the combined series which were treated conserva

tively while 6 out of 55 fractures in the Control Series treated with open reduction and internal fixation were primarily complicated by osteomyelitis The association of necrosis of the skin and osteomyelitis in 3 cases who had an operative incision through traumatized skin suggested the treatment adopted in the Prospective Series Here closed reduction was done and fixation was accomplished either by blind nailing or transfixation and plaster according to the type and location of fracture The results demonstrated the value of this treatment no case of infection was encountered in the Prospective Series

This investigation has shown that avoidance of incision through potentially damaged skin prevents infection and subsequent poor results in closed transverse fractures of the shaft of the tibia. However some of these fractures could probably have been treated equally well by closed reduction without internal fixation.

3 *Open Transverse Fractures*

Considerable confusion exists in the literature concerning the etiology of infection in open fractures of the shaft of the tibia. Four possibilities seem to be important in this respect

(a) that every open fracture by definition must be regarded as contaminated
(b) that an open wound left open is a potential portal of entry for pathogenic bacteria
(c) that the mechanism of fracture is such that the soft tissues (skin, fascia, muscle) have been severely crushed and may be partly devitalized
(d) that any foreign object for example a device for internal fixation may enhance the risk of infection or when infection is already present, may increase the severity of the infection.

The first two of these contentions were discussed by Essex Lopresti (1950) in his eloquent plea for early closure of the open wound in trauma He advanced evidence that contamination should not be equated with infection all bacteria are not pathogenic, and the tissues are equipped for handling bacterial invasion Essex Lopresti also showed that the risk of secondary contamination with pathogenic bacteria increases with the period of time a wound is left open Apparently the idea that excision of damaged soft tissue had priority over closure of the wound in open fractures gained acceptance during the First World War and received further emphasis from

internal fixation was high (37 of 47 fractures) the wound was enlarged in only 1 case Blind nailing was often used Only in 4 fractures all double fractures was the bone exposed in an area other than the wound All cases in which transplantation of skin was done as a primary procedure were treated with internal fixation None of those developed osteomyelitis

In this investigation it was thus not possible to demonstrate any relationship between the introduction of a metallic device for internal fixation and an increased hazard of complications (Table 13) even though such devices were used in cases with extensive soft tissue injuries

The results of this investigation are interpreted as follows *Presently available methods of skin transplantation make it possible to close most wounds in open fractures encountered in civilian practice* Also, the mechanical means for securing adequate, not necessarily firm, fixation of the fracture are readily available Perhaps internal fixation is more important in open than in closed fractures damaged skin or a skin graft needs a quiet bed to avoid undue pressure and permit early secondary transplantation of skin when needed

The skin and occasionally the skin graft showed signs of necrosis in 8 cases in the Prospective Series In view of the above it seemed reasonable to repair such areas with additional skin grafts in all cases The outcome of such procedures is interpreted as indicating the necessity for an active approach to the skin problem

In view of the higher risk for necrosis of the skin and osteomyelitis over age 45 (Bauer and Edwards 1965), special attention should be given to elderly individuals

C CORRELATION OF ANATOMY, ETIOLOGY AND THERAPY IN FRACTURES OF THE SHAFT OF THE TIBIA

In general definition of etiologic factors is a prerequisite for effective therapy and prevention of disease It was shown above that the anatomic classification used here corresponds to an etiologic classification of fractures of the shaft of the tibia Therefore an attempt was made (Bauer and Edwards 1966) to define the boundaries of choice of treatment of fractures of the shaft of the tibia on the basis of the anatomic classification It is seen (Fig 3) that one and the same Venn diagram may symbolize definition of etiology anatomy and therapy in fractures of the shaft of the tibia It should perhaps be stressed that the guidelines for treatment presented here define *restrictions* on choice of treatment rather than the *optimal* treatment For

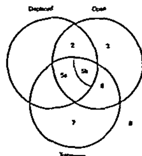


FIGURE 3 Restrictions imposed by attention to skin problem on choice of treatment of fracture of the shaft of the tibia.

Venn Diagram Area	Type of Fracture	Skin Problem
1	Displaced closed longitudinal	Skin does not restrict choice of treatment.
2	Displaced open longitudinal	Wound must not be left open (grafts need never be used) otherwise skin does not restrict choice of treatment.
4	Displaced closed transverse	Incision of skin over the fracture should be avoided
5 a	Displaced open transverse (wound < 6 cm)	Wound must not be left open. Grafts need hardly ever be used primarily but wound must be watched for signs of necrosis If necrosis develops secondary transplantation of skin may be needed Enlargement of wound should be avoided
5 b	Displaced, open, transverse (wound > 6 cm)	Wound must not be left open. These large wounds often need primary transplantation of skin, followed by secondary transplantation if areas of necrosis appear Graft bed probably improved by muscle graft and osteosynthesis

example, nothing in this investigation supports use of internal fixation of fractures of the shaft of the tibia However the investigation does show that it can be used, and how it can be used

D CENTRALIZED TREATMENT OF FRACTURES OF THE SHAFT OF THE TIBIA

Only because of rigid adherence for three years to the policy that one staff member was responsible for treatment of all fractures of the shaft of the tibia and immediate referral from other hospitals of fractures of the shaft of the tibia, was it possible to accumulate the material presented as the Prospective Series here

This policy appears to have resulted in immediate benefit to individual patients in terms of fewer complications, and the patients apparently did not find it too inconvenient to pass by their local hospital to receive continued treatment An important reason for this is explained by Fig 1, which shows the distance to Malmo from the hospitals involved expressed as driving time

Perhaps centralized treatment of certain types of fractures will become as much an accepted policy as is already the case for severe burns, anuria certain types of birth defects, and in certain areas pseudarthrosis of the tibia The results of this investigation indicate that the definition of cases of fracture of the shaft of the tibia which should be centralized may exclude longitudinal fractures Further refinement of definitions will lessen the pressure on the center, and minimize the competition between central and peripheral hospital units

As regards the necessity to provide all physicians in training with equal opportunities for learning management of fractures centralization will promote rather than prevent such opportunities the presence of a relatively high concentration of severe open fractures of the shaft of the tibia has had a stimulating effect upon all concerned in the management of such cases even though only one individual has been primarily responsible for all of these cases

V Conclusions

1 Infection is the most important causative factor in poor results of frac tures of the shaft of the tibia

2 Infection is directly related to secondary contamination through de vitalized areas of the skin

3 *Longitudinal fractures* generally caused by indirect moderate violence, are bound to give good results, treatment with internal fixation does not carry more risk of osteomyelitis than other elective procedures

4 *Transverse fractures* are generally caused by direct severe violence which may cause skin damage obvious in open fractures but severe also in closed fractures Choice of treatment of the fracture is limited by restrictions imposed by attention to the skin injury Closed methods with or without blind intramedullary nailing are preferred Skin in cisions should not be made through potentially damaged skin especially not over the subcutaneous antero medial surface of the tibia

5 In *open transverse fractures* the wound should be closed without delay avoiding tension and using pedicle or free skin grafts when necessary as a primary procedure Necrosis of skin or grafts should be aggressively treated by additional grafting procedures

VI Summary

A PURPOSE

The purpose of this investigation was to test the hypothesis that prognosis and optimal choice of treatment of fractures of the shaft of the tibia are related more to the extent of skin injury than to the extent of bone injury

B MATERIAL

The probands of this investigation were 483 adult patients with 492 traumatic fractures of the shaft of the tibia treated during a fifteen year period, 1949 1963 at the Orthopaedic Department of an urban community Fractures which involved the knee or ankle regions were not included in this material

Anatomically fractures with displacement belonged in three main groups, (a) closed longitudinal fractures, (b) closed, transverse fractures and (c) open, transverse fractures The transverse fractures included short oblique, comminuted, and double fractures and were caused predominantly by severe violence such as motor vehicle accidents, whereas the longitudinal fractures were caused predominantly by moderate violence such as falls at ground level or from low heights or bicycle accidents

The anatomic classification used here was thus closely correlated with the etiology of the fractures

The material was divided into two series (a) a *Control Series* of 311 fractures treated during the period 1949 1960, and (b) a *Prospective Series* of 181 fractures treated during the period 1961 1963

C TREATMENT

The general policy throughout the period of this investigation was to institute early definitive treatment, usually within 24 hours of injury Plaster from toes to groin was used in all fractures and internal fixation was used in 290 of 425 fractures which were reduced

The difference in treatment between the two Series depended on the main type of fracture

1 *Displaced Closed Longitudinal Fractures*

Throughout the period of this investigation the treatment of longitudinal fractures remained unchanged the frequency of internal fixation, usually with screws, was 85 % in markedly displaced fractures

2 *Displaced Closed, Transverse Fractures*

In the closed transverse fractures the frequency of internal fixation was equal in the two Series (56 of 94 in the *Control* and 32 of 62 in the *Prospective Series*) while the frequency of open reduction was higher *** in the *Control* (55/94) than in the *Prospective* Series (9/62) and the methods of internal fixation were different In the *Control Series* the most common type of internal fixation was a plate In the *Prospective Series* intramedullary nailing was preferred In the *Control Series* the plate was always placed on the antero-medial surface of the tibia with the incision in same area In the *Prospective Series* closed reduction and blind nailing was done in 23 of 28 nailed and when open reduction was deemed necessary the incision was placed so as to avoid the antero medial surface of the leg

3 *Displaced Open Transverse Fractures*

a Skin Injury

In the open transverse fractures in the *Control Series* the skin was always closed primarily A relaxing incision was done three times and skin grafts were never used

By contrast the guiding principle of treatment in the *Prospective Series* was primary closure of the skin with care to avoid tension Drainage was not used Immediate transplantation of the skin as pedicle or free grafts always combined with internal fixation was performed in 8 of 11 wounds over 10 cm in length and in 3 of 14 wounds between 6 and 10 cm in length transplantation of skin was not done in 22 wounds less than 6 cm in length

b Bone Injury

In the *Prospective Series* the choice of treatment of the bone injury as well was guided by the necessity to avoid additional damage to the skin In the *Control Series* 13 fractures were treated in traction This method was never used in the *Prospective Series* There was no significant difference in the frequency of internal fixation in the two series (37 of 71 in the *Control*

Series and 31 of 47 in the *Prospective Series*) In the *Control Series* internal fixation by means of a plate and/or screws was used in 30 of 37 fractures In the *Prospective Series* these methods were replaced with intramedullary nailing with a Rush pin (28/31) In 22 of these fractures the nail was used alone In 6 fractures additional fixation was provided by encircling wire Four of these were double fractures

D COMPLICATIONS

Complications considered in this investigation were necrosis of the skin and osteomyelitis

Thirty fractures had necrosis of the skin 16 *deep* (with exposure of bone) and 14 *superficial* (no exposure of bone)

Twenty two fractures developed osteomyelitis, 18 *severe* with drainage more than one year, and 4 *mild*

E FINAL STATUS

Follow up one year or longer was made in 95 % of the probands All probands who had had necrosis of the skin and/or osteomyelitis were available for evaluation Fourteen probands with other injury to the same limb were excluded from evaluation of Final Status The fracture of the shaft of the tibia healed in those excluded

Evaluation of Final Status was made with regard to subjective and objective signs of impaired function and the fractures were classified as *good fair* or *poor* Good implied complete resumption of normal activities, and poor implied poor functional status, severe complaints osteomyelitis with recurrent drainage, pseudarthrosis and amputation

F RESULTS

The results of this investigation were expressed in terms of (1) comparison of the Prospective and Control Series as regards complications Healing Time and Final Status in the three main fracture types and (2) correlation of the incidence of osteomyelitis with Healing Time and Final Status

1 *Comparison of Prospective Series with Control Series*

a Closed Displaced Longitudinal Fractures

The Final Status in the 149 longitudinal fractures was 83 % good and 17 % fair with little difference between the Control and the Prospective Series None of the fractures of this type had poor Final Status One com

plication only was observed a fracture in the Control Series with superficial necrosis of the skin The Healing Time for 95 % of the fractures was somewhat shorter in the Prospective as compared to the Control Series

b Closed Displaced Transverse Fractures

A marked difference between the Control and the Prospective Series was observed as regards incidence of osteomyelitis and Final Status in the closed transverse fractures

In the *Control Series* 7 out of 94 fractures developed osteomyelitis, 6 primary and 1 secondary In the *Prospective Series* none of 62 fractures developed osteomyelitis

In the entire material the Final Status was good in 75 % fair in 20 % and poor in 5 % None of the 7 fractures which were classified poor as regards Final Status occurred in the Prospective Series The Healing Time for 95 % of the fractures was shorter in the Prospective as compared to the Control Series

c Open Displaced Transverse Fractures

A marked difference between the Control and the Prospective Series was observed as regards incidence of osteomyelitis and Final Status in the open transverse fractures

In the *Control Series* 14 of 71 fractures developed osteomyelitis 13 primary and 1 secondary In the *Prospective Series* 1 of 47 fractures developed osteomyelitis

In the entire material the Final Status was good in 59 %, fair in 26 % and poor in 15 % Only 1 of the 15 fractures which were classified poor as regards Final Status occurred in the Prospective Series The Healing Time for 95 % of the fractures was markedly shorter in the Prospective as compared to the Control Series

d Other Fractures

The Final Status in the 47 fractures which did not belong to the three main fracture types was good in 46 and fair in 1 case The number of cases was too small to permit any comparison between the two Series

2 *Correlation of Osteomyelitis with Healing Time and Final Status in Transverse Fractures*

All of the 22 fractures with poor Final Status in this investigation occurred in displaced transverse fractures either open or closed, treated with open

reduction and internal fixation Fourteen of these 22 occurred in fractures complicated by osteomyelitis

a Fractures Complicated by Osteomyelitis

The difference between Control and Prospective Series in Healing Time was found to be due entirely to the higher incidence of osteomyelitis in the Control Series

The Final Status was classed as poor because of (i) *amputation* 3 fractures (all in the Control Series) were amputated because of chronic osteomyelitis In 2 of these the fracture had not healed, (ii) *chronic osteomyelitis* 4 fractures (all in the Control Series) had chronic osteomyelitis with drainage continuing over 4 to 10 years In 3 of these the Final Status was poor also because of marked ankle joint stiffness, (iii) *other criteria* 7 fractures (6 in the Control Series) were classed as poor because of severe stiffness of the ankle or foot with severe objective as well as subjective disability In no case was there severe limitation of knee motion

The incidence of osteomyelitis was higher*** in fractures with necrosis of the skin (16 of 30) than in those without necrosis of the skin (6 of 244) The incidence of osteomyelitis was higher** in fractures with deep necrosis of the skin (13 of 16) than in those with superficial necrosis (3 of 14) The incidence of severe osteomyelitis was higher*** in fractures with deep necrosis of the skin (12 of 16) than in fractures with superficial necrosis of the skin (1 of 14)

b Fractures Uncomplicated by Osteomyelitis

The final Status was classed as poor because of (i) *pseudarthrosis* 2 fractures in the Control Series did not heal, (ii) *other criteria* 6 fractures (all in the Control Series) were classed as poor, 2 fractures because of marked [illegible], to walk combined with pain, 4 fractures because of marked stiffness of the ankle joint with both subjective and objective disability

C CONCLUSIONS

1 Infection is the most important causative factor in poor results of fractures of the shaft of the tibia
2 Infection is directly related to secondary contamination through devitalized areas of the skin

3 *Longitudinal fractures* generally caused by indirect moderate violence, are bound to give good results treatment with internal fixation does not carry more risk of osteomyelitis than other elective procedures

4 *Transverse fractures* are generally caused by direct, severe violence which may cause skin damage obvious in open fractures but severe also in closed fractures Choice of treatment of the fracture is limited by restrictions imposed by attention to the skin injury Closed methods with or without blind intramedullary nailing are preferred Skin incisions should not be made through potentially damaged skin, especially not over the subcutaneous antero-medial surface of the tibia

5 In *open transverse fractures* the wound should be closed without delay avoiding tension and using pedicle or free skin grafts when necessary as a primary procedure Necrosis of skin or grafts should be aggressively treated by additional grafting procedures

VII Acknowledgments

Financial support was obtained from research grants awarded to Professor Goran C H Bauer from the U S Public Health Service (N I D R Grant No DE 1452, and General Support Branch, Grant No 1 SO1 FR 05495) and from the Swedish Medical Research Council, and to the author from Herman Jarnhardt's Stiftelse, Malmö, Fylgias 80 års fond Stockholm, and the Faculty of Medicine, the University of Lund

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IX Coded Data

A PROBANDS

CONTROL SERIES

A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	R	S	T	U	V
I	1	27	I	11	—	3	++	+	—	7^{0}	—	—	—	4	—	—	1	7	a
	2	27	I	11	—	3	++	+	—	7^{0}	—	—	—	3	—	—	1	8	b
	3	30	I	11	—	2	+	—	—	7^{0}	—	—	—	3	—	—	1	5	a
	4	31	I	11	—	3	++	+	—	7^{4}	—	—	—	3	—	—	6	11(3)	a
	5	31	I	11	—	3	++	+	—	7^{3}	—	—	—	4	—	—	2	15	b
	6	31	I	11	—	3	++	+	—	8^{0}	—	—	—	2	—	—	1	6	a
	7	32	I	11	—	3	++	+	—	7^{0}	—	—	—	3	—	—	1	7	a
	8	32	I	10	—	2	++	+	—	7^{0}	—	—	—	3	—	—	2	6	a
	9	34	I	11	—	3	++	+	—	7^{30}	—	—	—	5	—	—	4	9	a
	10	34	I	11	—	3	++	+	—	7^{33}	—	—	—	6	—	—	2	17	b
	11	35	F	11	—	3	++	+	—	10^{0}	—	—	—	3	—	—	2	5	a
	12	37	F	11	—	2	++	+	—	8^{0}	—	—	—	3	—	—	x	x	a
	13	38	I	11	—	3	++	+	—	8^{0}	—	—	—	3	—	—	1	6	a
	14	42	I	11	—	2	++	+	—	7^{0}	—	—	—	3	—	6 S	2	5	x*
	15	43	F	11	—	3	++	+	—	8^{0}	—	—	—	4	—	—	2	8	a
	16	43	F	11	—	3	++	+	—	7^{2}	—	—	—	1	—	—	1	7	a
	17	45	F	11	—	3	++	+	—	7^{0}	—	—	—	4	—	—	1	5	a
	18	45	F	10	—	3	++	+	—	10^{0}	—	—	—	2	—	—	3	7	a
	19	45	F	10	—	3	++	+	—	7^{0}	—	—	—	4	—	—	2	8	b
	20	47	I	11	—	3	++	+	—	8^{0}	—	—	—	3	—	—	2	12	b
	21	47	I	11	—	3	++	+	—	7^{0}	—	—	—	3	—	6 S	10	11	a
	22	47	F	11	—	3	++	+	—	7^{0}	—	—	—	3	—	—	3	5	b
	23	47	F	11	—	3	++	+	—	7^{0}	—	—	—	4	—	—	2	8	a
	24	49	F	11	—	3	++	+	—	7^{0}	—	—	—	5	—	6 S	2	9	b
	25	51	F	11	—	3	++	+	—	8^{0}	—	—	—	3	—	6 S	5	x	x*
	26	52	F	11	—	3	++	+	—	7^{0}	—	—	—	3	—	—	2	8	a
	27	52	I	10	—	3	+	—	—	7^{14}	—	—	—	3	—	—	11	9	a
	28	54	F	11	—	3	++	+	—	8^{0}	—	—	—	3	—	—	8	10	a
	29	55	F	11	—	2	++	+	—	7^{0}	—	—	—	4	—	—	5	13	a
	30	59	I	11	—	3	++	+	—	7^{5}	—	—	—	4	—	—	17	8	a
	31	59	I	10	—	3	++	+	—	7^{0}	—	—	—	4	—	9	8	8	[illegible]

32	64	F	11	—	2	++	+	—	8^2	—	—	—	4	—	6 S	11	9	a
33	64	F	11	—	3	++	+	—	7^2	—	—	—	2	—	—	8	8	x^+
34	64	F	11	—	3	++	+	—	7^0 10^0	—	—	—	4	—	—	6	7	a
35	73	F	11	—	3	++	+	—	8^0 10^0	—	—	—	4	—	—	x	x	a
36	74	F	11	—	3	++	+	—	7^0	—	—	—	2	—	—	1	4	a
37	78	F	11	—	2	++	+	—	7^0	—	—	—	2	—	—	2	11	x^+
38	80	F	11	—	3	++	+	—	8^2	—	—	—	2	(N)	—	14	5	a
39	39	Γ	11	—	3	++	+	—	1	—	—	—	7	—	—	1	27	b
40	40	F	11	—	3	++	+	—	1	—	—	—	3	—	—	y	x	a
41	41	F	11	—	3	++	+	—	2	—	—	—	5	—	9	8	8	a
42	45	F	11	—	3	+	+	—	1	—	—	—	2	—	—	1	4	b
43	47	F	11	—	3	++	+	—	1	—	—	—	3	—	—	1	4	a
44	49	F	11	—	3	+	+	—	0	—	—	—	2	—	4 S	2	4	x
45	50	F	11	—	3	+	+	—	0	—	—	—	2	—	—	1	6(2)	a
46	58	F	11	—	3	++	+	—	0	—	—	—	3	—	—	16	5	a
47	63	F	11	—	2	++	+	—	1	8^3	—	—	6	—	—	27	10	b
48	69	F	11	—	3	+	+	—	0	—	—	—	3	—	—	1	4	a
49	72	Γ	1	—	3	+	+	—	14	—	—	—	5	—	—	4	15	b
50	78	F	11	—	1	++	+	—	1	—	—	—	3	—	—	12	4	x^+
51	78	F	11	—	3	++	+	—	1	—	—	—	3	—	—	y	x	x^+
52	21	M	11	—	3	++	+	—	7^4	—	—	—	4	—	—	12	5	a
53	22	M	8	—	3	++	+	—	7^2	—	—	—	3	—	—	14	5	a
54	25	M	11	—	3	++	+	—	7^3	—	—	—	4	—	—	1	10	y^1
55	26	M	11	—	2	++	+	—	7^0	—	—	—	4	—	—	2	5	y^+
56	26	M	10	—	3	++	+	—	7^0	—	—	—	4	—	—	1	6(1)	y
57	28	M	11	—	3	++	+	—	7^0	—	—	—	3	—	—	10	4	a
58	28	M	1	—	3	++	+	—	7^0	—	—	—	2	—	—	6	5	a
59	30	M	10	—	3	++	+	—	7^0	—	—	—	3	—	—	4	6	a
60	33	M	11	—	3	++	+	—	7^0	—	—	—	3	—	—	9	9	b
61	33	M	11	—	2	++	+	—	7^{12}	—	—	—	2	—	—	2	7(1)	a
62	34	M	11	—	3	+	—	—	7^0	—	—	—	3	—	—	1	6	y^1
63	34	M	7	—	3	++	+	—	7^0	—	—	—	2	—	—	1	5	a
64	35	M	11	—	3	++	+	—	10^0	—	—	—	6	—	—	1	12	b
65	36	M	7	—	3	++	+	—	8^0 10^0	—	—	—	5	—	—	2	6	a
66	37	M	11	—	3	++	+	—	7^2	—	—	—	2	—	—	14	10	a
67	38	M	11	—	3	++	+	—	7^3	—	—	—	4	—	—	1	8	b

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
	68	38	M	11	—	3	++	+	—	7^0	—	—	—	4	—	—	5	11	b
	69	39	M	10		3	++	+	—	7^0	—	—	—	4(7)	—	—	5	11	v'
	70	40	M	11	—	3	++	+	—	7^0	—	—	—	4	—	—	1	7	a
	71	40	M	11	—	3	++	+	—	7^0	—	—	—	3	—	—	1	10(1)	b
	72	43	M	10	—	3	++	+	—	10^0	—	—	—	5	—	—	1	7	v+
	73	13	M	11	—	3	++	+	—	7^2	—	—	—	2	—	—	1	5	a
	74	13	M	11	—	3	++	+	—	7^0	—	—	—	2	—	—	2	6	b
	75	45	M	11	—	3	++	+	—	7^0	—	—	—	4	—	—	2	8	a
	76	45	M	3	—	3	++	+	—	7^0	—	—	—	3	—	—	3	6	a
	77	46	M	10	—	3	++	+	—	7^0 10^0	—	—	—	5	—	—	2	11	a
	78	46	M	7	—	3	++	+	—	7^0	—	—	—	4	—	—	4	10	b
	79	46	M	10	—	3	++	+	—	7^{16}	—	—	—	4	—	—	18	7	a
	80	17	M	11	—	3	+	+	—	7^0	—	—	—	3	—	—	1	5(2)	a
	81	47	M	1	—	3	++	+	—	10^0	—	—	—	3	—	—	2	7	a
	82	49	M	10	—	3	++	+	—	7^{11}	—	—	—	4	—	—	6	[illegible]	a
	83	49	M	10	—	3	++	+	—	7^6	—	—	—	3	—	—	1	4	a
	84	50	M	10	—	3	++	+	—	8^0	—	—	—	3	—	—	4	10	a
	85	50	M	11	—	3	++	+	—	7^0 10^0	—	—	—	6	—	—	2	14	a
	86	50	M	11	—	3	++	+	—	7^0	—	—	—	3	—	—	2	9	a
	87	51	M	11	—	3	++	+	—	7^0	—	—	—	3	—	—	1	7	v+
	88	52	M	11	—	3	++	+	—	7^{15}	—	—	—	4	—	—	3	10	a
	89	52	M	7	—	3	++	+	—	7^0	—	—	—	4	—	—	3	9	a
	90	53	M	11	—	3	++	+	—	7^2		—	—	4	—	—	16	10	b
	91	55	M	11	—	3	++	+	—	7^0	—	—	—	5	—	—	1	12	a
	92	56	M	10	—	3	++	+	—	7^0	—	—	—	5	—	—	1	13	a
	93	56	M	11	—	3	++	+	—	7^0	—	—	—	4	—	—	4	9	a
	94	57	M	11	—	3	++	+	—	7^0 8^0	—	—	—	5	—	—	8	11	a
	95	58	M	11	—	3	++	+	—	7^0	—	—	—	5	—	—	3	11	a
	96	58	M	11	—	3	++	+	—	7^2	—	—	—	3	—	—	1	7	a
	97	59	M	11	—	3	++	+	—	7^0	—	—	—	4	—	—	15	8	a
	98	60	M	11	—	2	++	+	—	8^8	—	—	—	5	—	—	3	9	a
	99	61	M	11	—	3	++	+	—	8^0	—	—	—	3	—	—	2	8	a

	100	62	M	3	—	3	++	+	—	7^0	—	—	—	4	—	—	3	9	a
	101	64	M	11	—	3	++	+	—	7^3	—	—	—	3	—	—	6	12	b
	102	64	M	11	—	3	++	+	—	7^0	—	—	—	3	—	—	12	6	a
	103	69	M	10	—	2	++	+	—	7^0	—	—	—	5	—	—	26	x	a
	104	73	M	11	—	3	++	+	—	7^0	—	—	—	4	—	—	4	10	a
	105	75	M	2	—	3	++	+	—	7^{12}	—	—	—	4	—	—	5	10	a
	106	77	M	7	—	3	++	+	—	7^0	—	—	—	2	—	2	24	x	a
	107	78	M	11	—	3	++	+	—	7^0	—	—	—	4	—	—	3	6	a
	108	16	M	11	—	2	++	+	—	1	—	—	—	5	—	—	1	7	a
	109	16	M	11	—	2	+	—	—	1	—	—	—	3	—	—	3	6	a
	110	18	M	3	—	3	++	—	—	1	—	—	—	4	—	—	4	6	a
	111	22	M	8	—	2	++	+	—	1	—	—	—	5	—	—	1	6	a
	112	36	M	11	—	3	+	+	—	1	—	—	—	3	—	—	1	4	a
	113	38	M	7	—	1	+	—	—	0	—	—	—	2	—	—	20	x	a
	(273)																		
	114	41	M	11	—	2	+	+	—	0	—	—	—	4	—	—	10	13	a
	115	45	M	11	—	2	+	+	—	0	—	—	—	4	—	—	1	7(2)	a
	116	49	M	10	—	3	++	+	—	1	—	—	—	5	—	—	12	9	b
	117	51	M	1	—	1	++	+	—	1	—	—	—	12	—	—	6	x	b
	118	63	M	10	—	2	++	+	—	2	—	—	—	3	—	—	11	5	a
2	119	28	Γ	11	—	3	++	+	be	7^0	—	—	—	4	—	—	2	7	a
	120	51	Γ	11	—	2	++	+	a	8^0	—	—	—	2	—	—	2	12	a
	121	74	Γ	1	—	1	++	+	b	1	—	—	—	3	—	—	24	9	a
	(147)																		
	122	?8	M	7	—	2	++	+	ce	7^0	—	—	—	3	—	—	11	5	a
	123	42	M	1	—	3	++	+	be	7^0	—	—	—	5	—	—	3	16	b
	124	5?	M	11	—	3	++	+	ae	7^0	—	—	—	3	—	—	3	5	a
	125	69	M	1	—	3	++	+	b	2	—	—	—	3	—	6 S	8	10(2)	x+
4	126	21	Γ	1	—	3	++	+	—	8^0	—	—	—	4	—	—	5	x	a
	127	23	Γ	1	—	2	++	+	—	8^{21}	—	—	—	4	—	—	4	13	b
	128	34	F	1	—	2	++	+	—	7^0	—	—	—	4	—	—	2	6	a
	129	40	Γ	3	—	3	++	+	—	9^3	—	—	—	11	—	—	20	15	a
	130	47	F	4	+	d	++/++	+	—	6^0	—	—	—	10(11)	—	—	13	21(13)	a
	131	56	Γ	1	—	1	++	+	—	8^0	—	—	—	5	—	—	5	31	a

CONTROL SERIES (cont)

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
4	132	57	F	4	—	1	++	+	—	8^{2}	$1^{6\ 13}$	—	—	20	—	—	11	36	b
	133	58	F	10	+	3	++	+	—	8^{55}	—	—	—	4	—	—	27	10	a
	134	59	F	1	—	2	++	+	—	7^{0} 13^{0}	—	—	—	5	—	9	28	x	b
	135	72	F	1	-	1	++	+	—	8^{14}	—	—	—	3	—	—	16	12	a
	136	72	F	1	+	2	++	+	—	5^{0}	—	—	—	3	—	1	5	11	a
	137	74	F	1	+	3	++	+	—	7^{0}	—	—	—	3	—	9	25	16	b
	138	74	F	1	+	1	++	+	—	6^{0} 10^{0}	—	—	—	3(8)	—	5 S	21	12	x*
	139	29	F	2	+	3	++	+	—	2	—	—	—	4	—	—	9	11	b
	140	44	F	1	—	2	+	+	—	3	—	—	—	6	—	—	2	13(1)	a
	141	55	F	1	—	3	++	+	—	4	—	—	—	6	—	8	20	x	b
	142	60	F	1	—	1	+	+	—	14	—	—	—	5	—	—	17	11	b
	143	60	F	11	+	3	++	+	—	1	—	—	—	3	—	—	20	8	b
	144	65	F	11	+	3	+	+	—	1	—	—	—	3	—	—	14	8	a
	145	72	F	11	—	3	+	+	—	1	—	—	—	4	—	—	19	6	a
	146	72	F	11	—	1	+	+	—	0	—	—	—	5	—	—	3	5	b
	147 (121)	74	F	1	—	1	++	+	—	3	—	—	—	5(7)	—	9	24	9	a
	148	81	F	1	—	1	++	+	—	1	—	—	—	5	—	9	25	13	a
	149	16	M	7	—	2	++	+	—	8^{0}	—	—	—	3	—	—	2	5	a
	150	16	M	8	—	2	++	+	—	7^{0}	—	—	—	3	—	—	2	7	a
	151	17	M	3	—	3	++	+	—	8^{0}	—	—	—	3	—	—	2	4	a
	152	18	M	3	—	2	+	—	—	8^{5}	—	—	—	3	—	6 S	12	9	x*
	153	18	M	2	—	2	++	+	—	8^{0}	—	—	4^{5}	3(9)	(NO)	—	6	11	a
	154	19	M	11	—	2	++	+	—	8^{9}	—	—	—	3	—	—	3	8	a
	155	19	M	1		2	++	+	—	8^{0}	—	—	—	5(7)	—	—	1	10	a
	156	20	M	2	—	2	++	+	—	9^{0}	—	—	—	4	—	—	4	5	a
	157	21	M	2	—	3	++	+	—	7^{3}	—	—	—	5	—	—	6	7	a
	158	21	M	1	—	2	++	+	—	8^{0}	—	—	—	6	—	—	4	9	a
	159	21	M	3	—	2	++	+	—	8^{0}	—	—	—	3	—	4 S	8	7	a
	160	22	M	2	—	3	++	+	—	8^{0}	—	—	—	4	—	—	1	9	a
	161	23	M	2	—	3	++	+	—	8^{0}	—	—	—	2	—	—	1	7	a
	162	25	M	2	—	2	++	—	—	8^{9}	—	—	—	4	—	—	1	8	a

163	26	M	2	—	3	++	+	—	8^{0}	7^{8} 10 11 17	—	—	16	O	—	6	31	b
164	27	M	8	—	3	++	+	—	9^{2}	—	—	—	4	—	—	2	5	a
165	27	M	2	—	3	++	+	—	8^{17}	—	—	—	3	—	6 S	10	4	a
166	28	M	10	—	2	++	+	—	8^{0}	—	—	—	4	—	—	6	11	x^{1}
167	28	M	2	—	2	++	+	—	8^{2}	—	—	—	3	—	—	6	7	a
168	28	M	7	—	3	+	+	—	8^{0}	—	—	—	4	—	—	2	9	a
169	31	M	2	—	1	+	—	—	8^{0}	—	—	—	3	—	—	4	7	a
170	31	M	8	—	3	++	+	—	8^{0}	—	—	—	3	—	—	2	6	a
171	35	M	1	—	1	++	+	—	8^{0}	—	—	—	7	—	—	1	10	a
172	37	M	6	+	2	++	+	—	8^{0}	—	—	—	2	—	—	4	12(6)	a
173	38	M	2	—	3	++	+	—	7^{0}	—	—	—	8(10)	—	—	16	15	a
174	41	M	7	+	d	++/++	+	—	7^{0}, 8^{0} 10^{0}	—	—	—	3	—	—	4	11	b
175	43	M	7	+	d	0/++	+	—	8^{0}	—	—	—	4	—	—	2	11	b
176	46	M	3	—	3	++	+	—	8^{8}	—	—	—	4	—	—	3	8	a
177	46	M	11	—	3	++	+	—	8^{0}	—	—	—	2	—	6 S	4	8	a
178	47	M	11	—	3	++	+	—	8^{10}	—	—	—	4	—	—	3	7	a
179	49	M	1	—	3	++	+	—	8^{0}	—	—	—	5	—	—	1	8	a
180	50	M	1	—	2	++	+	—	9^{30}	—	—	—	4	—	3 S	18	15	x^{1}
181	52	M	11	—	1	++	+	—	8^{0}	—	—	—	3	—	—	2	4	a
182	53	M	7	—	1	++	—	—	8^{0}	—	—	—	4	—	—	7	9	a
183	57	M	7	+	3	+	+	—	10^{20}	7^{11} 13 15 22	—	—	9	O	—	7	P	c (O)
184	60	M	1	—	2	++	+	—	8^{0}	—	—	—	5(7)	—	6	20	21 P	c
185	63	M	2	+	2	++	+	—	8^{0}	—	—	—	4	—	—	2	13	a
186	65	M	7	+	3	++	+	—	8^{0}	1^{8} 30 48 7^{44} 60 10^{70}	—	—	33(54)	NOS**	—	80	P	c (amp)
187	65	M	1	—	2	+	+	—	8^{0}	7^{5} 10	—	—	7(12)	NO	—	50	40 P	c
188	66	M	10	+	3	++	+	—	7^{0} 10^{0}	7^{6}	—	1^{3}	8	NO	—	36	12	b
189	71	M	1	—	3	++	+	—	7^{0}	—	—	—	4	—	—	18	13	a
190	76	M	1	+	1	++	+	—	8^{0}	1^{5}	—	—	13	—	—	49	P	c (ps)
191	84	M	1	+	d	+/++	+	—	8^{3}	—	—	—	3(7)	O	8	11	P	c (O)
192	16	M	2	—	3	+	+	—	0	—	—	—	2	—	—	1	4	b
193	16	M	3	+	3	++	+	—	3	—	—	—	5	—	—	2	6	a
194	17	M	3	—	2	+	—	—	1	—	—	—	3	—	—	1	4	a
195	18	M	8	—	2	++	+	—	3	—	—	—	4	—	—	1	6	a
196	18	M	8	—	2	+	+	—	1	—	—	—	3	—	—	1	4	a

** primary complications —

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
4	197	21	M	2	+	3	+	+	—	1	—	—	—	3	—	—	2	7	a
	198	27	M	1	—	2	++	+	—	3	—	—	—	5	—	8	5	10 P	b
	199	23	M	3	+	2	+	+	—	2	—	—	—	3	—	—	9	5	a
	200	25	M	8	—	2	++	+	—	4	—	—	—	5	—	—	7	10	b
	201	29	M	8	—	3	++	+	—	3	—	—	—	5	—	—	2	12	b
	202	31	M	1	—	3	++	+	—	1	—	—	—	4	—	6	4	8	a
	03	39	M	7	—	2	++	+	—	3	—	—	—	7	—	—	10	15(1) P	b
	204	41	M	1	+	2	+	+	—	1	—	—	—	3	—	—	1	8	x[1]
	205	42	M	2	—	3	+	+	—	1	—	—	—	6	—	—	1	11	a
	206	43	M	1	+	d	0/+	+	—	1	—	—	—	3	—	—	2	8	x*
	207	43	M	1	+	d	++/0	+	—	3	—	—	—	7	—	6 S	2	10	a
	208	44	M	3	+	2	++	+	—	3	—	—	—	4	—	—	2	6	a
	209	44	M	7	—	2	++	+	—	3	—	—	—	6	—	6	2	12	a
	210	47	M	2	—	2	++	+	—	1	5[4]	—	—	9	—	8	4	17	a
	211	52	M	1	—	3	++	+	—	3	—	—	—	5	—	—	9	12	b
	212	52	M	1	—	3	++	+	—	4	—	—	—	4	—	8	12	11(5)	b
	213	55	M	7	—	3	++	+	—	1	6[5]	—	—	13	—	—	4	19	a
	214	55	M	7	—	1	+	—	—	0	—	—	—	3	—	—	3	7	a
	215	55	M	7	+	2	+	+	—	1	—	—	—	3	—	—	15	10	b
	216	56	M	11	+	3	++	+	—	3	—	—	—	4	—	—	1	9	a
	217	66	M	1	+	1	++	+	—	1	—	—	—	5	—	—	16	14 P	b
	218 (290)	9	M	1	—	1	++	+	—	4	—	—	—	8(11)	—	—	44	P	c
	219	84	M	11	—	1	+	+	—	1	—	—	—	2	—	—	1	x	x*
5	220	29	F	1	—	2	++	+	a	5[9]	—	—	—	3	—	—	3	5	a
	221	30	F	1	—	2	++	+	b	8[9]	—	—	—	3	—	1	6	11	b
	222	41	F	1	—	3	++	+	bf	9[10]	—	—	—	5	—	—	8	11	a
	223	45	F	1	+	d	0/+	+	a	8[15]	—	—	—	3	—	—	5	18(8)	b
	224	72	F	1	—	2	++	+	ce	10[0] 13[9]	—	1	—	6	—	—	17	8	a
	225	17	F	1	—	2	++	+	ce	3	9[27]	1	—	6	(N)	—	10	17	b
	226	25	F	6	—	3	++	+	[illegible]	[illegible]									

227	48	F	11	—	2	++	+	cef	11	—	—	—	8	—	—	4	16	a
228	70	F	1	—	3	++	+	ce	1	—	—	—	4	—	—	20	11 P	c
229	72	F	1	—	2	++	+	b	13	—	—	—	7(9)	—	—	32	19	b
230	86	F	1	—	2	+	+	d	3	—	—	—	4	—	9	10	6	a
231	17	M	2	—	3	++	+	b	8^{0}	—	—	—	2	—	8	2	7(4)	a
232	18	M	3	+	2	++	+	a	8^{0}	—	—	—	7(12)	—	—	1	14	a
233	19	M	1	+	2	++	—	be	7^{0}	7^{2} 9^{76}	—	—	6	(NO)	9	14	16	b
234	20	M	2	—	3	++	+	b	8^{29}	—	—	—	6	—	—	21	8	x^{1}
235	22	M	2	—	2	++	+	c	8^{0}	1^{8}	—	—	10(12)	(N)	—	10	14	a
236	28	M	7	—	3	++	+	b	8^{30} 9^{30}	—	—	—	3	N	—	9	19	a
237	29	M	2	—	2	++	+	a	9^{21}	—	—	—	3	—	2S 1S	20	7	a
238	32	M	?	—	2	++	+	a	8^{0}	—	—	—	2	—	—	1	7	b
239	35	M	2	+	3	++	+	b	9^{7}	—	—	—	4	—	—	3	8	a
240	37	M	7	—	2	+	—	a	8^{30}	—	—	—	6	—	—	13	10	b
241	39	M	6	—	2	++	+	ae	8^{35}	—	—	—	6	—	9	2	8	b
242	42	M	7	—	3	++	+	a	8^{0}	—	—	—	3	—	—	2	8	a
243	42	M	1	+	d	++/++	+	a	8^{0} 8^{0}	—	—	—	7	—	—	6	14	a
244	43	M	2	—	2	++	+	a	7^{0}	—	—	—	3	—	8 3S	36	24	x^{2}
245	44	M	2	+	3	++	+	ae	8^{0}	—	—	—	2	—	—	4	8	a
246	46	M	3	+	3	++	+	be	7^{0}	—	—	—	3	—	—	11	5	a
247	46	M	7	+	d	0/++	+	a	7^{15}	—	—	—	4	—	—	6	11	a
248	47	M	7	+	3	+	+	c	8^{0}	$7^{7\ 8\ 36}$	—	8^{1}	35(40)	NO	—	60	43 P	c
249	48	M	2	+	d	++/++	+	def	7^{6}	$7^{5\ 13}$	1	—	7	NO	9	28	19	c
250	48	M	3	—	3	++	+	b	8^{0}	8^{36}	—	8^{40} 4^{48}	3	N(O)	6S 7S	37	41	x^{3}
251	51	M	2	—	2	++	+	b	9^{10}	—	—	—	8	(O)	—	17	15	b
252	54	M	2	—	2	++	+	de	7^{0}	6^{22}	—	8^{4} $4^{5\ 6\ 2}$ 3^{10}	25(29)	NO	8	64	40 P	c (O)
253	54	M	2	+	2	++	+	a	8^{0}	1^{4} $7^{6\ 10}$ 3^{15} 2^{20} 10^{77}	—	8^{4}	26	NO	—	53	36 P	c (amp)
254	54	M	5	+	2	++	+	def	8^{0}	$1^{3\ 12\ 15}$ 7^{9} 3^{12}	—	—	39	NO*S	—	153	P	c
255	56	M	2	+	3	++	+	ce	7^{0}	—	—	4^{4}	14	(N)	—	20	31 P	c (ps)
256	57	M	1	—	2	++	+	de	7^{0}	—	—	—	6	—	—	6	24 P	b
257	58	M	1	—	2	++	+	a	8^{30}	7^{39}	—	—	5(12)	O	—	56	30 P	c (O)
(259)																		

* primary complications (N)

CONTROL SERIES (cont)

A	B	C	D	Γ	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
5	258	58	M	11	—	3	++	+	ce	7^{0}	—	—	—	4	—	—	2	7	a
	259	58	M	1	+	2	++	+	a	8^{21}	—	—	—	6	—	—	56	30 P	c
	(257)																		
	260	64	M	7	+	2	++	+	b	8^{0}	—	—	—	4	—	—	8	11	a
	261	69	M	1	—	3	++	+	b	8^{0}	—	—	—	7	—	—	8	9	x+
	262	74	M	1	+	d	+/++	+	be	7^{0} 8^{0}	—	—	—	3	—	—	7	15	a
	263	16	M	10	—	2	+	—	b	1	—	—	—	4	—	—	2	8	a
	264	16	M	3	+	3	+	—	ce	2	1^{5} 8^{14} ^{38}	—	—	6	—	—	13	36	b
	265	19	M	2	—	3	++	+	a	1	—	—	—	3	—	8 9	6	7	a
	266	22	M	2	—	2	+	+	b	1	—	—	—	4	—	8	18	7	a
	267	24	M	2	+	2	++	+	c	2	—	—	—	9	—	—	6	18 P	b
	268	25	M	7	+	3	++	+	b	2	1^{6}	—	—	14	—	—	—	23	b
	269	25	M	6	+	1	++	+	b	3	—	—	—	6	—	9	3	10	b
	270	26	M	2	—	2	+	+	cef	2	—	—	—	3	—	1, 9	4	5	a
	271	30	M	2	—	3	+	+	b	1	—	—	—	5	—	—	2	6	a
	272	31	M	2	+	d	++/++	+	be	2	—	—	—	6(10)	—	6 S	30	17 P	x+
	273	33	M	7	+	d	+/++	+	be	1	1^{23}	—	—	16(25)	—	4 S	20	34 P	b
	(113)																		
	274	38	M	3	—	2	++	+	de	3	—	—	—	14	(N)	—	16	17 P	b
	275	41	M	7	—	3	++	+	be	1	—	—	—	3	—	—	9	9(2)	a
	276	41	M	7	+	2	+	—	a	1	—	—	—	3	—	—	4	6	x+
	277	44	M	1	+	1	++	+	b	2	7^{3}	—	—	10	NO	—	33	15	a
	278	44	M	1	+	2	++	+	a	2	—	—	—	6	—	—	9	10	b
	279	44	M	1	—	2	++	+	a	1	—	—	—	4	—	—	8	7	a
	280	45	M	2	—	2	++	+	c	2	—	—	4^{13}	6	(N)O	4 S 9	25	10 P	c
	(281)																		
	281	45	M	2	+	1	++	+	b	2	—	—	—	3	—	—	25	10	b
	(280)																		
	282	47	M	7	+	3	++	—	de	2	7^{3} 10^{9}	—	4^{2} ^{4}	9	NO	—	44	P	c (amp)
	283	51	M	6	+	3	++	+	ce	1	—	—	—	4	(N)	9	30	x	a
	284	56	M	7	—	3	++	+	def	2	—	—	4^{2} ^{3} ^{3}	17	NO	—	39	36 P	c
	285	58	M	6	—	2	++	+	a	11	—	—	—	5	—	8	6	9	a

	286	58	M	1	+	2	+	+	b	2	—	—	—	7	O	—	29	20	a
	287	64	M	1	+	3	++	+	be	3	—	—	—	11	(N)	—	13	23(5)	b
	288	67	M	7	+	d	0/++	+	a	2	—	—	—	10	—	—	52	30 P	c
	289	76	M	1	—	3	++	+	ce	14	—	—	—	8(11)	—	—	21	x	x^+
	290	79	M	1	—	1	++	+	a	4	—	—	—	8(11)	—	—	44	P	c
	(218)																		
6	291	39	F	1	—	2	0	+	b	0	—	—	—	3	—	—	1	6	a
	292	31	M	4	—	2	0	—	a	0	—	—	—	4	—	—	11	15	a
	(293)																		
	293	31	M	4	+	3	0	—	a	0	—	—	—	4	—	7 S	11	15	x'
	(292)																		
	294	43	M	1	—	2	0	+	a	0	—	—	—	2	—	—	5	9	a
7	295	47	F	1	—	2	0	—	—	3	—	—	—	5	—	—	1	10(1)	a
	296	16	M	3	—	3	0	—	—	0	—	—	—	3	—	—	3	4	a
	297	16	M	2	—	1	0	—	—	1	—	—	—	2	—	—	1	3	x'
	298	17	M	1	—	1	0	+	—	0	—	—	—	3	—	—	1	5	a
	299	18	M	2	—	2	0	—	—	0	—	—	—	4	—	—	1	8	a
	300	18	M	7	—	2	0	—	—	0	—	—	—	2	—	—	7	3	a
	301	18	M	2	—	3	0	—	—	0	—	—	—	2	—	—	4	3	a
	302	21	M	2	+	2	0	—	—	1	—	—	—	5	—	—	18	8	a
	303	22	M	4	—	3	0	—	—	0	—	—	—	7	—	—	7	12	a
	304	24	M	8	—	2	0	—	—	0	—	—	—	2	—	—	7	6	x'
	305	25	M	8	—	2	0	—	—	0	—	—	—	3	—	—	1	4	a
	306	26	M	8	—	2	0	—	—	0	—	—	—	2	—	—	10	5	a
	307	26	M	8	—	3	0	—	—	0	—	—	—	5	—	—	2	6	a
	308	27	M	8	—	2	0	—	—	0	—	—	—	2	—	—	—	3	a
	309	29	M	8	—	2	0	+	—	1	—	—	—	2	—	—	2	3	a
	310	41	M	8	—	2	0	—	—	0	—	—	—	3	—	—	2	5	a
	311	43	M	1	—	2	0	—	—	0	—	—	—	3	—	8	3	6(1)	x^+

PROSPECTIVE SERIES

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
1	1	16	F	9	—	3	++	+	—	7°	—	—	—	2	—	—	1	3	a
	2	42	I	9	—	3	++	+	—	7°	—	—	—	3	—	—	5	6	b
	3	44	F	11	—	3	++	+	—	7°	—	—	—	4	—	—	1	8	a
	4	45	I	11	—	3	++	+	—	7°	—	—	—	3	—	—	1	6	b
	5	46	I	9	—	3	++	+	—	7°	—	—	—	2	—	—	2	4	a
	6	19	F	11	—	3	++	+	—	7°	—	—	—	3	—	—	2	11	a
	7	19	F	11	—	3	++	+	—	7°	—	—	—	4	—	—	20	7	r
	8	52	F	11	—	3	++	+	—	7°	—	—	—	3	—	—	1	5	a
	9	53	F	11	—	3	++	+	—	7°	—	—	—	2	—	—	6	5	a
	10	55	F	11	—	3	++	+	—	5°	—	—	—	3	—	6S	2	6	a
	11	60	F	11	—	3	++	+	—	10°	—	—	—	2	—	—	3	10	r
	12	70	F	11	—	3	++	+	—	7° 10°	—	—	—	3	—	—	x	x	x*
	13	23	I	9	—	3	+	—	—	0	—	—	—	2	—	—	0	6	r
	14	29	I	11	—	3	+	—	—	0	—	—	—	3	—	—	0	5	r
	15	37	F	11	—	3	+	+	—	0	—	—	—	3	—	—	0	5	r
	16	43	F	11	—	3	+	+	—	0	—	—	—	2	—	—	0	4	a
	17	56	F	1	—	3	+	+	—	0	—	—	—	2	—	9	11	4	a
	18	56	F	11	—	3	++	+	—	3	—	—	—	5	—	—	3	11	a
	19	70	I	1	—	3	++	+	—	3	—	—	—	3	—	—	22	12	b
	(123)																		
	20	88	F	11	—	3	+	—	—	0	—	—	—	3	—	—	0	x	a
	21	22	M	11	—	3	++	+	—	7°	—	—	—	4	—	—	2	5	r
	22	24	M	9	—	3	++	+	—	7°	—	—	—	4	—	—	2	8	a
	23	34	M	11	—	3	++	+	—	7°	—	—	—	4	—	—	4	x	a
	24	36	M	11	—	2	++	+	—	7°	—	—	—	3	—	—	2	4	r
	25	38	M	10	—	3	++	+	—	7°	—	—	—	3	—	—	1	5	a
	26	39	M	6	—	3	++	+	—	7°	—	—	—	2	—	7 S 9	24	x	x*
	27	41	M	11	—	3	++	+	—	10°	—	—	—	4	—	—	1	9	a
	28	42	M	6	—	3	++	+	—	7°	—	—	—	2	—	—	1	9	a
	29	42	M	11	—	3	++	+	—	7°	—	—	—	3	—	—	1	x	a
	30	43	M	7	—	3	++	+	—	7°	—	—	—	2	—	—	1	5	b
[illegible]	[illegible]	43	M	11			+	+	—										

1	31	43	M	11	—	3	++	+	—	7^0		—	—	—	3	—	—	2	5	a
	32	45	M	11	—	3	++	+	—	7^0		—	—	—	2	—	—	2	5	r
	33	46	M	11	—	3	++	+	—	7^0		—	—	—	2	—	—	1	5	a
	34	51	M	11	—	2	++	+	—	7^0		—	—	—	2	—	—	1	7	a
	35	53	M	3	—	2	++	+	—	10^0		—	—	—	3	—	6S	5	6	a
	36	58	M	11	—	2	++	+	—	7^0		—	—	—	2	—	—	1	6	a
	37	59	M	6	—	3	++	+	—	7^0		—	—	—	3	—	6S	1	8	a
	38	59	M	11	—	3	++	+	—	7^0		—	—	—	2	—	—	1	6	a
	39	60	M	10	—	3	++	+	—	10^0		—	—	—	3	—	—	2	7	r
	40	63	M	11	—	3	++	+	—	10^0		—	—	—	2	—	—	3	7	r
	41	16	M	2	—	1	++	—	—	3		—	—	—	3	—	—	3	5	r
	42	17	M	9	—	2	+	—	—	0		—	—	—	2	—	—	1	3	r
	43	18	M	9	—	3	+	+	—	0		—	—	—	2	—	—	0	4	r
	44	46	M	11	—	3	++	+	—	1		—	—	—	3	—	—	1	5	r
	45	46	M	11	—	3	++	+	—	3		—	—	—	4	—	—	1	8	r
	46	47	M	11	—	3	++	+	—	3		—	—	—	3	—	—	3	8	r
	47	54	M	3	—	3	++	+	—	3		—	—	—	3	—	—	4	9	r
2	48	[illegible]7	Г	11	—	2	++	+	a	5^0		—	—	—	2	—	—	2	5	r
	49	74	Г	11	—	3	++	+	r	7^0		—	—	—	2	—	6S	6	x	x⁺
	50	52	M	10	—	3	++	+	b	7^0		—	—	—	3	—	9	3	5	a
	51	21	M	3	—	1	+	+	b	1		—	—	—	7	—	—	6	10	r
	52	89	M	5	—	3	+	—	b	0		—	—	—	3	—	—	4	5	r
4	53	19	Г	4	—	2	++	+	—	5^0		—	—	—	4	—	1 9	6	7	a
	54	41	Г	4	+	d	++/++	+	—	6^0	10^0	6^8	—	—	10	—	1 9	7	23(5)	b
	55	62	Г	1	—	[illegible]	++	+	—	5^0		—	—	—	3	—	—	3	6	a
	56	72	Г	1	—	2	++	+	—	5^0		—	—	—	3	—	—	3	7	r
	57	77	Г	1	—	2	++	+	—	5^0		6^7	—	—	8(10)	—	—	11	11	r
	58	60	Г	11	—	3	+	+	—	3		—	—	—	3	—	—	3	12	b
	59	73	Г	1	—	1	++	—	—	1		—	—	—	3	—	9	14	8	r
	60	74	Г	11	—	1	+	+	—	0		—	—	—	4	—	—	4	7	r
	61	82	Г	11	—	3	+	+	—	0		—	—	—	3	—	—	x	x	a
	62	16	M	7	—	2	++	+	—	5^0		—	—	—	3	—	—	2	5	a
	63	16	M	8	—	3	++	+	—	5^0		—	—	—	2	—	—	4	4	a

PROSPECTIVE SERIES (cont)

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
1	64	17	M	8	—	2	++	+	—	6^0	—	—	—	4	—	—	1	8	a
	65	18	M	7	—	3	++	+	—	6^0	—	—	—	5	—	—	1	8	a
	66	20	M	2	—	2	++	+	—	5^0	—	—	—	5	—	—	2	13	a
	67	22	M	8	—	2	++	+	—	5^0	—	—	—	4	—	—	1	5	a
	68	22	M	8	—	3	++	+	—	5^0	—	—	—	2	—	—	1	5	a
	69	23	M	8	—	2	++	+	—	5^0	—	—	—	5	—	—	1	6	a
	70	24	M	8	—	2	++	+	—	5^0	—	—	—	2	—	—	1	4	a
	71	24	M	4	+	2	++	+	—	7^0	—	—	—	2	—	—	2	6	a
	72	25	M	1	—	3	++	+	—	5^0	—	—	—	3	—	—	1	6	r
	73	28	M	8	—	2	++	+	—	5^0	6^8	—	—	11	—	—	2	8	b
	74	29	M	8	—	2	++	+	—	5^0	—	—	—	3	—	—	2	6	a
	75	30	M	1	—	2	++	+	—	5^0	—	—	—	5	—	9	12	6	a
	76	41	M	11	—	2	++	+	—	5^5	—	—	—	3	—	—	3	6	r
	77	50	M	7	—	2	++	+	—	5^0	—	—	—	3	—	—	1	7	a
	78	51	M	7	—	2	++	+	—	5^0	—	—	—	7	—	—	2	12	a
	79	51	M	11	—	3	++	+	—	5^0	—	—	—	3	—	9	3	8	a
	80	52	M	7	+	d	0/++	+	—	5^0	—	—	—	3	—	—	2	7	a
	81	53	M	2	—	2	++	+	—	6^0	—	—	—	3	—	—	2	14	a
	82	55	M	4	+	d	++/++	+	—	6^0 10^0	—	—	—	5	—	—	2	10	a
	83	57	M	1	+	d	0/++	+	—	7^0	—	—	—	1	—	—	2	10	a
	84	57	M	1	—	2	++	+	—	5^0	—	—	—	5	—	8	2	11	a
	85	60	M	1	+	2	++	+	—	5^0	—	—	—	4	—	9	9	8	r
	86	61	M	1	+	2	++	+	—	7^0	—	—	—	2	—	—	8	13	b
	87	63	M	2	—	2	++	+	—	5^0	—	—	—	4	—	—	2	7	a
	88	79	M	1	—	3	++	+	—	7^0	—	—	—	8	—	—	1	10	a
	89	16	M	2	—	3	++	+	—	1	—	—	—	3	—	—	1	5	r
	90	17	M	2	—	1	+	—	—	1	—	—	—	3	—	—	0	7	a
	91	17	M	2	—	3	++	+	—	1	—	—	—	3	—	—	2	5	r
	92	17	M	2	—	3	++	+	—	3	—	—	—	3	—	—	2	6	a
	93	17	M	3	+	3	+	—	—	0	—	—	—	2	—	—	0	3	a
	94	19	M	4	+	2	++	+	—	3	—	—	—	4	—	5	14	8	a
	95	21	M	2	+	d	++/++	+	—	3	6^6	—	—	10	—	—	5	20	b

4	96	21	M	8	—	3	+	—	—	1	—	—	—	5	—	—	1	6	a
	97	25	M	2	—	3	+	—	—	0	—	—	—	4	—	—	0	7	a
	98	28	M	8	—	2	+	+	—	1	—	—	—	2	—	—	2	5	a
	99	29	M	2	—	2	+	—	—	1	—	—	—	4	—	5S	3	10	a
	100	30	M	8	—	2	+	—	—	0	—	—	—	5	—	—	2	10	a
	101	31	M	1	—	2	++	+	—	3	—	—	—	3	—	—	3	6	a
	102	32	M	7	—	3	++	+	—	3	—	—	—	4	—	—	2	8	a
	103	34	M	8	—	2	+	—	—	0	—	—	—	2	—	—	0	5	a
	104	34	M	1	+	d	0/++	+	—	3	—	—	—	4	—	—	1	7	a
	105	37	M	8	—	2	+	+	—	1	—	—	—	6	—	—	1	11	a
	106	39	M	7	—	2	+	—	—	0	—	—	—	3	—	—	0	6	a
	107	54	M	10	+	3	++	+	—	3	—	—	—	4	—	—	4	9	b
	108	61	M	1	—	3	++	+	—	1	—	—	—	3	—	—	1	9	b
	109	63	M	1	—	3	+	—	—	0	—	—	—	2	—	—	0	5	a
	110	64	M	10	+	1	+	+	—	1	—	—	—	3	—	—	16	8	a
	111	69	M	1	+	1	+	+	—	0	—	—	—	4	—	9	2	12	a
	112	72	M	1	+	2	++	+	—	3	—	—	—	11	—	—	52	16	b
	113	73	M	1	+	2	++	+	—	3	—	—	—	4	—	2S	38	16	a
	114	77	M	1	—	3	++	+	—	3	1^4	—	—	7	—	—	6	11	a
5	115	16	Γ	2	—	2	++	+	b	5^0	—	—	—	3	—	—	2	4	a
	116	35	Γ	1	+	d	++/++	+	def	6^0 10^0	—	2	—	4	—	—	6	10	a
	117	64	Γ	1	+	2	++	+	de	6^0 10^0	6^7	—	—	10	—	—	10	15	b
	118	65	Γ	1	+	2	++	+	def	10^0 12^0	1^6	—	—	9	—	5	34	13	b
	119	80	Γ	1	+	3	++	+	de	6^0	—	6	—	4	—	—	5	6	a
	120	37	Γ	4	—	3	+	+	a	3	—	—	—	2	—	5 6S 7 9	x	x	a
	121	56	Γ	11	—	3	+	—	ce	0	—	—	—	4	—	—	2	8	a
	122	62	Γ	1	—	3	++	+	ce	3	—	—	—	4	—	—	2	9	a
	123	70	Γ	1	—	3	++	+	be	3	—	—	—	4	—	—	22	12	b
	(19)																		
	124	16	M	2	—	2	++	+	b	5^0	—	—	—	3	—	—	1	6	a
	125	22	M	5	—	2	++	+	ce	5^0	—	—	4½	3	(N)	—	4	6	a
	126	24	M	2	—	1	++	+	be	5^0	—	—	—	3	—	6S	2	10	a
	127	26	M	2	—	2	++	+	a	6^0	6^{22}	—	—	8(25)	—	—	3	15(6)	a
	128	30	M	7	—	2	++	+	c	5^0	—	—	—	3	—	9	x	x	a
	(130)																		

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
5	129	30	M	7	—	2	++	+	c	5^0	—	6	—	4	—	—	2	9	a
	130 (128)	30	M	7	+	2	++	+	de	6^0 10^0	4^3	5	4^{1} ^{3} 3^{2}	9	N	3S	x	x	x^a
	131	31	M	7	—	2	++	+	bef	5^0	—	—	—	5	—	3S 5S 6	11	16	x^a
	132	31	M	1	+	d	++/++	+	a	6^0 10^0	—	—	—	5	—	5S 6S 8	10	x	x^a
	133	35	M	1	—	2	++	+	c	6^0	—	2	—	3	—	—	3	5	a
	134	35	M	7	—	2	++	+	a	5^0	—	—	—	3	—	—	2	6	a
	135	37	M	1	—	2	++	+	ce	5^0	—	—	4^1	6	N	—	7	14	a
	136	41	M	6	+	3	++	+	a	5^0	—	—	—	4	—	—	2	8	a
	137	51	M	1	—	3	++	+	b	7^{10}	1^{11}	—	—	14	—	—	3	17	a
	138	55	M	6	+	2	++	+	a	5^0	6^6	—	—	8	—	—	6	16	a
	139	56	M	1	+	2	++	+	de	6^0	6^4	3	4^1	12	(N)	—	6	22	b
	140	58	M	1	+	3	++	+	de	7^0 12^0	1^9	7	—	13	—	9	14	18	b
	141	61	M	7	—	2	++	+	ce	5^0	—	—	4½	7	(N)	6S	4	16	a
	142	65	M	3	—	1	++	+	a	5^0	—	—	—	4	—	—	2	9	a
	143	69	M	2	+	2	++	+	ce	6^0	—	—	4^1	7	(N)	—	6	12	a
	144	71	M	1	+	d	++/+	+	be	6^0 10^0	—	—	—	7	—	9	6	12	b
	145	72	M	7	—	3	++	+	de	6^0	1^{14}	5	—	11(18)	—	—	4	20	a
	146	75	M	2	+	d	++/++	+	c	6^0 10^0	6^7	4	—	12	—	—	21	17	b
	147 (148)	77	M	7	—	2	++	+	de	6^0	—	5	—	4	—	—	11	12	a
	148 (147)	77	M	7	—	2	++	+	de	6^0	—	5	—	8	—	—	11	12	a
	149	78	M	7	—	2	++	+	b	5^0	—	—	—	3	—	—	1	8	a
	150	16	M	2	—	3	++	+	ce	1	—	—	—	3	—	—	1	4	a
	151	16	M	2	+	2	++	+	b	3	—	—	—	3	—	—	2	5	a
	152	19	M	2	—	3	++	+	c	3	6^5	—	—	9	—	—	5	14	b
	153	20	M	2	—	3	++	+	b	3	—	—	4^1	4	(N)	1	6	14	a
	154	20	M	2	+	3	++	+	ce	3	6^5	—	—	12	—	3S	34	x	x^a
	155	21	M	2	+	1	++	+	def	14	7^8 ^{17} 8^{31}	—	3^2	27	N O	9S	30	38 P	c
	156	21	M	4	—	2	+	—	b	0	—	—	—	3	—	3	9	8	a
	157	[illegible]	M	7	—	3	++	+	b	1	—	—	—	4	—	—	1	7	a

	158	29	M	6	—	2	++	+	r	3	—	—	—	5	—	7 9S	x	x	x
	159	41	M	1	+	3	++	+	ce	3	17	—	—	12	—	2	10	16	b
	160	55	M	2	+	3	++	+	b	3	—	—	—	5	—	8	3	13	a
	161	59	M	7	—	3	++	+	b	3	—	—	—	3	—	—	3	6	a
7	162	16	M	2	—	2	0	+	—	0	—	—	—	4	—	—	1	7	a
	163	16	M	2	—	3	0	+	—	0	—	—	—	2	—	9	2	3	a
	164	16	M	7	—	3	0	—	—	0	—	—	—	2	—	—	0	2	a
	165	17	M	3	—	2	0	—	—	0	—	—	—	1	—	—	1	3	r
	166	17	M	3	+	2	0	—	—	0	—	—	—	2	—	—	4	3	a
	167	18	M	8	—	2	0	+	—	0	—	—	—	3	—	—	1	7	a
	168	18	M	8	—	3	0	—	—	0	—	—	—	2	—	—	0	3	a
	169	37	M	8	—	2	0	—	—	0	—	—	—	2	—	—	0	4	a
	170	37	M	7	+	1	0	—	—	0	—	—	—	3	—	—	0	7	a
	171	55	M	1	—	1	0	—	—	0	—	—	—	3	—	—	0	4	a
	172	66	M	3	—	1	0	—	—	0	—	—	—	3	—	—	1	4	r
8	173	21	F	11	—	2	0	+	—	0	—	—	—	2	—	—	1	3	r
	174	53	F	11	—	3	0	+	—	0	—	—	—	2	—	—	8	6	r
	175	59	F	11	—	3	0	—	—	0	—	—	—	3	—	—	0	4	a
	176	74	F	1	—	2	0	—	—	0	—	—	—	2	—	—	3	4	a
	177	17	M	8	—	2	0	—	—	0	—	—	—	2	—	—	0	3	r
	178	17	M	8	—	2	0	—	—	0	—	—	—	2	—	—	2	3	a
	179	17	M	11	—	3	0	—	—	0	—	—	—	2	—	—	0	3	a
	180	27	M	11	—	3	0	—	—	0	—	—	—	3	—	—	0	6	a
	181	41	M	3	—	3	0	—	—	0	—	—	—	2	—	—	0	3	a

B NON PROBANDS
WHO WERE RESIDENTS OF MALMÖ

CONTROL SERIES

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
1	1a	30	I	6	—	3	++	+	—	10	—	—	—	?	—	3S, 8 9	?	?	?
	2c	76	I	11	—	3	++	+	—	8	—	—	—	2	—	—	14	4	?
	3c	57	I	11	—	1	+	+	—	0	—	—	—	3	—	—	17	?	?
	4c	74	I	11	—	3	++	+	—	2	—	—	—	3	—	—	8	?	?
	5c	78	F	11	—	3	++	+	—	1	—	—	—	4	—	—	1	?	?
	6a	28	M	4	—	2	++	+	—	10	—	—	—	4	—	3S 9	?	?	?
	7a	29	M	11	—	3	++	+	—	10	—	—	—	?	?	?	?	?	?
	8a	30	M	11	—	3	++	+	—	7	—	—	—	2	—	—	1	4	?
	9a	30	M	9	—	2	++	—	—	7	—	—	—	3	—	—	2	6	?
	10a	42	M	2	—	3	++	+	—	10	—	—	—	3	—	4S 5S	2	10	?
	11g	16	M	11	—	3	++	+	—	7	—	—	—	—	—	—	2	—	—
	12a	46	M	?	—	3	++	?	—	10	—	—	—	?	?	?	?	?	?
	13c	75	M	11	—	2	++	+	—	7	—	—	—	6	—	—	—	3	c (ps)
	14g	77	M	1	—	3	++	+	—	7	—	—	—	—	—	—	—	6	—
	15a	21	M	10	—	3	+	?	—	1	—	—	—	3	—	—	1	10	?
	16a	27	M	11	—	3	+	+	—	1	—	—	—	3	—	—	1	6	?
	17d	31	M	6	—	1	+	+	—	0	—	—	—	?	—	3S 8 9	?	?	?
	18e	33	M	11	—	2	+	—	—	1	—	—	—	3	—	—	2	9	?
	19c	10	M	11	—	3	+	?	—	2	—	—	—	2	—	—	6	?	?
?	20c	15	I	11	—	3	++	+	b	10	—	—	—	3	—	—	20	7	a
	21a	18	F	4	—	3	++	+	c	2	—	—	—	5	—	8	8	?	?
	22a	40	M	3	—	2	++	+	?	10	—	—	—	4	?	—	?	?	?
4	23g (43)	75	I	1	—	2	++	+	—	8	—	—	—	—	—	1 8 9	<1	—	—
	24a	26	F	4	+	2	+	—	—	0	—	—	—	3	—	1 9	14	9	?
	25e	36	F	11	—	2	+	—	—	1	—	—	—	2	—	—	6	4	a
	26a	45	F	4	+	2	+	+	—	1	—	—	—	7	—	—	2	10	a
	27c	51	I	11	—	3	+	+	—	1	—	—	—	2	—	—	22	11	?
	28a	17	M	4	—	2	++	+	—	6	—	—	—	2	—	3 8 9	10	?	?
	29a	25	M	8	—	2	++	+	—	8	—	—	—	4	—	—	1	6	?

4	30a	40	M	?	+	3	++	?	—	6 10	7	—	—	10	N?O	—	12	?	?
	31a	51	M	10	+	d	0/++	+	—	9	—	—	—	5	—	—	13	?	?
	32a	16	M	1	—	2	++	+	—	1	—	—	—	4	—	—	3	7	?
	33a	19	M	8	—	2	+	+	—	1	—	—	—	3	—	—	3	5	a
	34a	19	M	3	—	3	+	+	—	0	—	—	—	3	—	—	6	5	a
	35e	21	M	11	—	3	++	+	—	3	—	—	—	6	—	—	3	9	?
	36a	24	M	8	—	2	+	+	—	1	—	—	—	4	—	—	4	9	?
	37a	28	M	7	+	1	+	+	—	1	—	—	—	3	—	—	3	5	?
	38g	31	M	4	—	1	+	?	—	0	—	—	—	—	—	8, 9	<1	—	—
	39a	34	M	4	—	3	+	?	—	1	—	—	—	4	—	—	1	6	?
	40a	36	M	6	—	3	++	+	—	1	—	—	—	4?	—	7 S	11	?	?
	41a	40	M	2	+	1	+	+	—	1	—	—	—	3	—	—	14	5	a
	42a	41	M	2	—	3	++	+	—	2	—	—	—	7	—	—	3	?	?
	43e	12	M	11	+	1	+	+	—	0	—	—	—	3	—	—	3	7	?
	44a	60	M	10	+	3	+	+	—	0	—	—	—	3	—	—	2	9	?
	45a	61	M	1	+	3	++	+	—	2	—	—	—	4	—	8 9	?	10	?
	46a	62	M	7	—	3	++	+	—	1	—	—	—	9	—	9	44	?	?
	47d	69	M	11	—	1	+	?	—	?	—	—	—	?	?	3 S	?	?	?
5	48g (?3)	75	F	1	+	2	++	+	b	—	—	—	—	—	—	8 9	<1	—	—
	49a	21	M	2	—	2	++	+	?	8	—	—	—	3	—	—	14	9	?
	50a	??	M	?	—	3	++	+	a	8	—	—	—	9	—	6 S	4	16	a
	51e	36	M	2	—	3	++	+	a	7	—	—	—	3	—	—	6	6	?
	52a	41	M	2	—	2	++	+	?	6	—	—	—	3	—	—	?	11	?
	53a	46	M	9	+	3	++	+	?	10	—	—	—	5	—	—	10	15	?
	54g	67	M	2	—	3	++	+	b	8	—	—	—	—	—	1	<1	—	—
	55a	18	M	3	+	2	+	+	?	1	—	—	—	3	—	8	?	5	?
	56a	19	M	1	+	2	++	+	?	1	7	—	?	?	NO	8	?	?	?
	57a	21	M	1	+	3	++	+	b	2	—	—	—	5	—	—	14	?	?
	58a	24	M	3	+	3	++	+	?	2	1 8	—	4	11	NO	—	30	?	c
	59a	31	M	4	+	2	++	+	?	2	—	—	—	9	—	—	12	11	?
	60a	45	M	1	—	3	++	+	b	3	—	—	—	—		—	3		—
	61g	69	M	1	+	3	++	+	?	1	—	—	—	—	—	1 9	—		—
	62g	83	M	1	+	3	++	+	b	3	—	—	—	—	—	8 9	<1	—	—
8	63c	3?	M	11	—	3	0	—	—	0	—	—	—	1	—	—	?	7	?

Letters under B referred to table 1

PROSPECTIVE SERIES

A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	R	S	T	U	V
1	1a	46	F	11	—	2	+	+	—	0	—	—	—	3	—	—	1	?	?
	2a	30	M	11	—	3	++	+	—	7	—	—	—	2	—	—	?	5	a
	3a	50	M	1	—	3	++	+	—	7^{17}	—	—	—	3	—	4 S 8	?	?	?
	4a	42	M	11	—	3	+	—	—	1	—	—	—	4	—	—	?	?	?
	5c	14	M	11	—	1	0	—	—	0	—	—	—	2	—	—	—	4	?
2	6g	75	F	6	—	3	++	+	—	3	—	—	—	—	—	—	3	—	—
4	7a	72	F	10	—	2	++	+	—	5	—	—	—	3	—	—	2	8	a
	8g	34	M	2	—	2	++	+	—	5	—	—	—	—	—	—	1	—	—
	9a	17	M	1	—	2	++	+	—	2	—	—	—	5	—	8	?	9	a
	10a	27	M	7	—	2	+	+	—	1	—	—	—	3	—	—	1	4	?
	11a	10	M	4	—	1	+	+	—	0	—	—	—	5(8)	—	6 S 4	?	14	?
	12c	57	M	1	—	1	+	+	—	1	—	—	—	6	—	—	11	8	?
5	13a	29	F	4	—	2	+	+	b	1	—	—	4	3		—	3	12	a
	14a	17	M	4	+	2	++	+	d	3	—	—	8 24	5	N	—	?	?	?
	15a	21	M	2	+	1	+	+	a	2	—	—	—	3	—	—	?	?	?
	16a	21	M	7	+	2	+	—	a	0	—	—	—	3	—	—	—	?	?

Letters under B referred to table 1

G *Location of Fracture*

1 p m l tl i d f t bi
2 m ddle tl d of t b a
3 d tal tl d of t bia
d d bl f a tu e

H *Displacement*

0 n d pl ement
\+ m d at d pl ceme t
\+\+ ma ked d plac m t
In d ble f tures tl l ft s g s d c t tl pro mal fract re

I *Fracture of Fibula*

\+ f ct e of f b la
— o f a t re of f b la

K *The Si e of Wound Exposure of Fracture and Contamination with Foreign Material*

a 1 cm or le s
b 2—5 cm
c 6—10 cm
d m e tl 10 cm of skin def ct
e e p re of fra t re
f tam nation with f e gn mat ial

L *Primary Treatment of Fracture (small figures represent days after the accident)*

0 d ct n a d plaster fixati n
1 cl ed d t on a d pla ter fix ti n
2 cl d d cti n a d traction followed w th plast r f xation
3 cl d *duct on a d t an fi tion*
4 cl d r d t a d e mpressi n t e tme t
5 l ed red tl n a d t rnal fixation with a R h p n
6 op r d t o a d l t rnal fix ti n with a R h pl or a Kunt cher na l
7 ope r ductio a d int rnal fi ation w th sc ws

N c o of tl skin (d ep)
(O) l gl t t omyel t s
O e teomyel t s

S *Other Fractures or Injuries (S other fractures to the same limb)*

1 f t e f the pel is
2 f act re f th e k of tl e f m r
3 f act r of the l aft f tl f mur
4 fract re f tl e p t lla
5 f a ture f tl e tib al plate u
6 f a t i e of tl e ankle
7 f t re of tl e foot
8 i jury of tl e l ad
9 otl s r inj ies

T *Hospitali ation (weeks)*

x t a ailable f evaluat on

U *Disability (months)*

First f gu e t tal disab lity
F gure in brack ts 50 % di ab l ty
N t a a lable f al at n
P P ion

V *Final status*

a g d
b fair
poor amp =amp tatio o=cl ronic o teomyel tis with d a nage
ps=p udartl os s
n t a labl for evalu ti n
t trac able
x+ de d
x¹ otl er fr ctu es t tl e same l mb
x² d abetic gangrene

X Reproductions of Colour Photographs and Radiographs

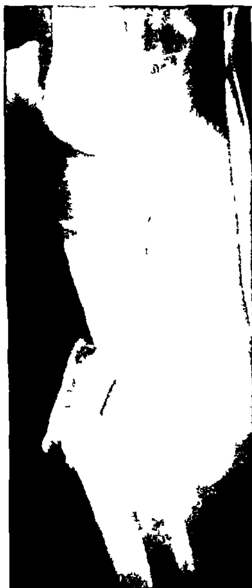




Photographs on admission immediately after accident

CASE 116 PROSPECTIVE SERIES

A 35 year old woman was run over by a car. One of the wheels went across her right lower leg. There was a large laceration involving the medial and posterior part of the calf and the popliteal fossa. Immediate operation with internal fixation and skin transplantation was performed.




X rays on admission showed a markedly displaced double fracture



3 weeks after the accid nt



10 months after the accident

}

Following exci ion of devitalized ti sue there was a large d fect It wa found pos ible to mobilize the skin from the lateral side of the leg over the front of the tibia so that the fracture region was covered with full thickness kin The defect medially and posteriorly was covered with plit thickness graft

5 months after the accident

Internal fixation was done with a Rushpin and encircling wire Immobilization in plaster was continued for 4 months she returned to work after 10 months The final status was good with a full range of motion of knee and ankle joints



There was a large wound with wide exposure of a comminuted fracture



After internal fixation a muscle graft was sewn over the entire fracture region

CASE 140 PROSPECTIVE SERIES

A 58 year old man run over by a car. One of the wheels crossed his left leg. Patient was admitted and operated immediately after the accident.



Comminuted fracture with partial loss of bone along 12 cm of the shaft of the tibia



The wound has been sutured



The defect created late has been covered with graft

After a relaxing incision had been made laterally and the flap had been undermined the wound could be closed without tension. The defect created by the relaxing incision was covered with split thickness graft.

Photographs 10 days after the accident when the wounds were rebandaged for t f st time



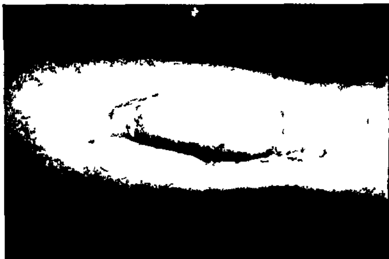


X rays immediately after operation

Shortening was minimized by fixation of the largest of the intermediary fragments with a screw. A second screw was placed in the fibula in order to stabilize the fracture



The wound 15 months after the accident



The grafted relaxing incision 15 months after the accident

X rays 13 months after the accident

9 months after the accident a bone graft was placed across the fracture

The fracture was immobilized in plaster for 13 months The patient resumed work after 18 months The final status was fair with full range of motion of knee and ankle joints but with a shortening of 1½ cm

ÅKE AHLBERG

Haemophilia in Sweden

VII Incidence, Treatment and Prophylaxis of Arthropathy and other Musculo-Skeletal Manifestations of Haemophilia A and B

Acta Orthopaedica Scandinavica
Supplementum No 77
Munksgaard Copenhagen 1965

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM NO 77

From the Orthopaedic Research Laboratories (Former Head Goran C H Bauer M D) of the Orthopaedic Department (Former Head Sophus von Rosen M D Present Head Anders Hulth M D) and *the Coagulation Laboratory (Head Inga Marie Nilsson M D)*
University of Lund Malmo General Hospital Malmo Sweden

Haemophilia in Sweden

VII Incidence, Treatment and Prophylaxis of Arthropathy and other Musculo-skeletal Manifestations of Haemophilia A and B

BY ÅKE AHLBERG

MUNKSGAARD COPENHAGEN 1965

Translated by L. James Brown
Printed in Sweden
Berlingska Boktryckeriet
Lund 1965

Contents

I General Introduction

John C Otto (1803) is credited with the first fairly detailed description of a disease characterised by a bleeding tendency and affecting only males but transmitted by females The name haemophilia for this disease was coined in the 1820s by Johann L Schönlein (Hopff 1828) For a number of years this term was used synonymously with haemorrhaphilia (fondness of bleeding) of which it is probably an abbreviation (Brinkhous 1965) In 1936 Patek and Taylor demonstrated the lack of a certain protein fraction of the plasma in haemophiliacs They called this factor antihaemophilic globulin This factor is now known as AHF (antihaemophilic factor) or factor VIII and it is the factor that is deficient in classical haemophilia A In 1947 Pavlovsky *et al* (1950) found that blood from one haemophiliac normalised blood from another patient with haemophilia Similar observations were also reported by Koller *et al* (1950) Biggs *et al* (1952) and Aggeler *et al* (1952) and it was concluded that there existed besides classical haemophilia a coagulation defect due to deficiency of another plasma protein This resulted in the distinction of two types of haemophilia namely A and B The new haemophilic factor was called haemophilia B factor Christmas factor or factor IX

In the 1860s Volkmann (Vegas 1914) pointed out that joint symptoms may occur in haemophilia and scurvy In 1892 Konig published a detailed report of the joint changes in haemophiliacs He described 2 patients who died from haemorrhage after operation for what was erroneously believed to be tuberculosis of the knee joint Feissley (1924) recommended the use of blood and plasma transfusions in the treatment of haemophiliacs Such infusions have since been widely used and the development of this form of therapy has been reviewed by Brinkhous (1964) But as late as 1956 DePalma and Cotler warned against surgical correction of joint deformities in patients with severe haemophilia

Haemophilia has been the subject of extensive research in Sweden Skold (1944) introduced blood transfusion therapy for treatment of haemophilia in Sweden He pointed out the value of transfusions of fresh blood as a

TABLE 1 Earlier investigations of haemophilic arthropathy

Author	Published Year	No of Cases	Coagulation Studies	Material
Thomas H B	1936	98	Incomplete	Examined at Research and *Educational Hospital and the* Illinois Surg Inst for Children 1930—1935
Ghormley R K and Clegg R S	1948	76	Incomplete	Examined at Mayo Clinic 1920—1939
Davidson C S *et al*	1949	40	Not described	Treated at Thorndike Memorial during a period of 10 years
DePalma A F and Cotler J	1956	117	Classified in four degrees Not described	Registered at the Jefferson Medical College Hospital
Rodnan G P *et al*	1957	53	Incomplete	
Jordan H H	1958	110	Not described	Treated at Lenox Hill Hospital New York City 1946—1956
Jones E W	1958	110	Not described	Registered at South Californa chapter of the Haemophiliac Society
Webb J B and Dixon A S	1960	42	24 completely investigated	Examined following request sent to 77 known haemophiliacs in London and the Home Countries
Crock H V and Boni V	1960	21	Incomplete	Treated at Nuffield Orthopaedic Centre Oxford
Crock H V	1962	30	Incomplete	Treated at Nuffield Orthopaedic Center Oxford during a period of 15 years
Arnold W D	1962	25	Not described	Treated at New York Hospital Pediatric Department and the Pediatric Hematology Clinic
Present Study	[illegible]	242	Complete coagulation studies	Representative for all Sweden

prophylaxis in connection with operations and orthopaedic measures on bleeders He also published an epidemiological study which was later followed by a similar investigation by Nilsson *et al* (1961) In the latter publication the haemophiliacs are classified according to the type and severity of the disease The heredity and symptomatology of haemophilia have also been analysed (Ramgren *et al* 1962 Ramgren 1962 a)

A method for the production of a concentrated preparation of human antihaemophilic factor (AHF) or fraction I—0 was described by Blomback and Blomback (1956) Nilsson (1957), Blomback *et al* (1960) This preparation has been used to control haemorrhage in patients with haemophilia A and to enable surgical operations (Blombäck and Nilsson 1958 Nilsson *et al* 1960 Nilsson *et al* 1962 Nilsson 1965)

Arthropathy and other musculo-skeletal complications are the commonest causes of disability of haemophiliacs Previous investigations of the disabling effect of such complications are based on clinical material from various hospitals and collected during a limited period (Table 1) It would appear that so far no attempts have been made to ascertain the incidence of arthropathy in a well defined population

The present investigation is based on previous work of haemophilia in Sweden Its main purpose was to ascertain the incidence of arthropathy and other musculo-skeletal manifestations and to devise principles of non surgical and surgical treatment as well as the prophylaxis of such lesions with the aid of coagulation correcting preparations

II Material and Methods

POPULATION OF SWEDEN AND PUBLIC RECORDS

In 1963 the population of Sweden was 7 6 million, of which about five sixths (6 4 million) were living in the southern half of the country Sweden is well suited for epidemiological studies because the population is fairly homogenous and because detailed public records have for many years been kept of all births marriages deaths (including the main causes of death) and changes of address Epidemiological surveys on osteogenesis imperfecta (Smars 1961) and on fracture of the femur (Dencker 1963) may serve as illustrative example of the suitability of Sweden in this respect

INCIDENCE OF HAEMOPHILIA IN SWEDEN

Nilsson *et al* (1961) charted the incidence of hameophilia in Sweden and gave a list of all known haemophilic families and individuals classified according to type and degree of the disease This list has been kept up to date and on January 1 1964 it contained 230 families (Addendum p 99) It is unlikely that this investigation has missed any individuals above 5 years with severe or moderate haemophilia

CLASSIFICATION OF HAEMOPHILIA

All individuals in the above mentioned list are classified regarding type and degree of haemophilia in accordance with the principles of Nilsson *et al* (1961) A distinction is made between haemophilia A and haemophilia B and within each of these types the degree of the disease is classified according to the plasma content of AHF (haemophilia A) or B factor (haemophilia B) as *severe moderate* or *mild* (Table 2)

Coagulation tests

All the methods used for collection and preparation of the blood samples and for determination of the different coagulation factors have been described elsewhere (Nilsson *et al* 1961)

assification of haemophilia

AHF or B-factor in per cent of normal
< 1
1 < 5
5—25

TABLE 3 Error of tests

Plasma sample	No of determinations	AHF value	
		Mean %	S D
1 (O D)	24	0 74	± 0 3
2 (P N a)	20	0 89	± 0 1
2 (P N a)	20	0 93	± 0 1
3 (P N b)	24	2 57	± 0 6
4 (B R)	24	2 92	± 0 7
5 (P N c)	20	5 78	± 1 4
6 (I R)	20	21 0	± 4.5
6 (I R)	20	19 8	± 5 0
7 (P G)	20	37 6	± 5 2

The *AHF activity* of plasma was assessed by its normalizing effect on the recalcification time of platelet rich haemophilia A plasma containing less than 1 per cent AHF (Nilsson *et al* 1957 Nilsson *et al* 1961) The amount of AHF present was expressed in per cent of that found for a normal standard consisting of pooled plasma from 10 normal individuals New standard plasma was prepared every week and the plasma of the patients was tested within one week after withdrawal of the blood A standard curve was plotted for each assay

The *haemophilia B factor activity* of the plasma was assessed by its normalizing effect on the recalcification time of haemophilia B plasma (Nilsson *et al* 1961) and the amount of haemophilia B factor present expressed in per cent of that found for a normal standard consisting of pooled plasma from 10 normal individuals

Error of Tests

Repeated AHF determinations were made on different plasma samples with AHF up to about 38 per cent of normal and the standard deviation was calculated (Table 3) At AHF values below 1 per cent of normal the standard deviation was ± 0 1 — ± 0 3 per cent and at AHF values between 2 and 3 per cent it was ± 0 6 — ± 0 7 per cent

As another example of the reliability and reproducibility of the method it might be mentioned that when one and the same preparation of frac

tion I—0 was given to the same patient on two different occasions re markably good agreement was noted between the total increase of AHF activity in the plasma of the patient on the two occasions The standard deviation of a single determination was found to be 11 5 per cent Good agreement was also found between the increase of AHF in two patients treated on different occasions with the same AHF preparation The stand ard deviation of a single determination was found to be 14 per cent (Blom back *et al* 1960)

PATIENTS

Selection of Patients

The investigation is based on all haemophiliacs in Sweden registered on Jan 1 1964 (Addendum p 99) The patients were examined (a) clini cally by the author (b) roentgenologically and/or (c) by questionnaire

The clinical and roentgenologic examinations were made at twelve hos pitals in ten towns (Fig 1) Of the 157 patients 76 were examined at Malmo General Hospital and then usually in association with the in vestigation of their haemophilia The remaining 81 patients were examined at their local hospitals Patients with mild haemophilia were requested to present themselves for clinical examination only if they lived near the examination centres

Completeness of Survey

Of 116 patients with *severe* haemophilia 95 were examined clinically Table 4) Seven of the 21 who were not examined were below 5 years of ge they failed to appear for examination because the parents felt either hat they were free from arthropathy or that they should not be bothered Of the remaining 14 above 5 years information about 7 was obtained by questionnaire No reply was obtained in the remaining 7 cases

Of 65 patients with *moderate* haemophilia 38 were examined clinically Table 4) Another 21 of those 65 answered the questionnaire Six patients with moderate haemophilia were unavailable for examination and/or failed o answer the questionnaire 3 of those 6 were below 5 years

Of 127 patients with *mild* haemophilia 24 were examined clinically Table 4) Another 57 of those 127 answered the questionnaire

The age distribution of patients investigated was about the same as that of the entire series (Table 5)

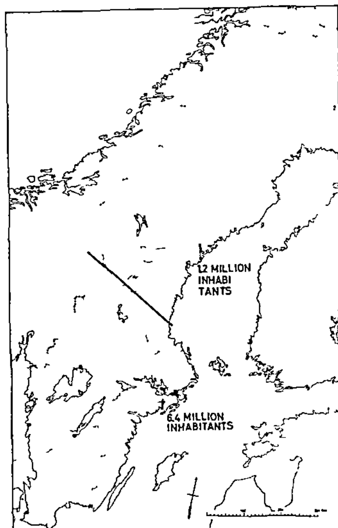


FIGURE 1 Sweden Hospitals where haemophiliacs were examined

TABLE 4 Distribution of material

	Haemophilia A			Haemophilia B			
Type of Haemophilia	Severe	Moderate	Mild	Severe	Moderate	Mild	Total
Personally examined	69	28	17	26	10	7	157
Questionnaire only	7	20	45	0	1	12	85
Not evaluated	14	3	38	0	3	8	66
Total	90	51	100	26	14	27	308

TABLE 5 Patients in different age classes

Age in Years	0—9	10—19	20—29	30—39	40—49	> 49	Total
Personally examined	37	42	31	19	15	13	157
Questionnaire only	6	18	19	15	11	16	85
Not evaluated	14	5	14	10	10	13	66
Total	57	65	64	44	36	42	308

METHODS OF INVESTIGATION

Clinical Examination

All clinical examinations were done by the author personally The examination included the hands and feet, and the following joints hip knee, ankle, shoulder elbow and wrist The gross configuration was studied and any deformity (valgus varus subluxation rotation defect), increase in breadth of epiphyses capsular thickening or muscular atrophy was noted The range of passive motion of the joints was measured Loss of range of motion was estimated when possible by comparison with the mobility of the contralateral joint The normal ranges of motion published by Hjortsjo (1959) were used as references

Hip Flexion was measured with the knee bent Normal range of extension flexion according to Hjortsjo 115°—125°

Abduction and adduction were measured with the hip joint extended Normal range about 45° and 25° respectively

Outward and inward rotation were measured with the hip joint flexed 90° Normal range about 60° and 30° respectively

Knee Extension flexion was measured Normal range about 160°

Ankle (including the talo crural and subtalar joints) Dorsal and plantar flexion as well as pronation and supination were noted Normal ranges dorsal flexion about 20° plantar flexion about 40° pronation supination about 45°

Shoulder The purpose of the examination was to assess the mobility of the humeroscapular joint Abduction with the scapula fixed normally about 90° Rotation was measured with the arm abducted 90° Normal range about 110°

Elbow (including the distal radio ulnar joint with which it forms a functional unit) Normal extension flexion 130 —140° Pronation and supination was measured with the elbow flexed 90° Normal range about 150°

Wrist Volar and dorsal flexion as well as radial and ulnar deviation were studied Normal ranges volar 80°—90° dorsal 50°—60° radial about 20° ulnar about 45°

Roentgen Examination

As a rule the patients were also examined roentgenologically (Chapter IX) The examinations were done at 12 hospitals (Fig 1), and no attempt was made to standardise the exposure conditions The roentgenologic

TABLE 6 Questionnaire used in examination for disability in haemophilia

Draw circle round correct answer	Right	Left
Can you put your hand behind your neck?	yes no	yes no
Can you reach your back with your hand?	yes no	yes no
Can you reach your mouth?	yes no	yes no
Can you use knife and fork?	yes no	yes no
Can you open a water faucet?	yes no	yes no
Can you turn a key?	yes no	yes no
Can you put on stocking and shoe?	yes no	yes no
Can you walk upstairs?	yes	no
Can you walk downstairs?	yes	no
Can you climb a chair with		
(a) right leg first?	yes	no
(b) left leg first?	yes	no
Can you walk more than 100 meters without stopping	yes	no
Can you walk more than 1000 meters without stopping?	yes	no
Can you walk out of doors without a cane?	yes	no
Do you use one cane out of doors?	yes	no
Do you use two canes out of doors?	yes	no
Do you use crutches out of doors	yes	no
Do you use braces?	yes	no
Do you use orthopaedic shoes?	yes	no
Do you use a wheelchair?	yes	no
Are you always confined to bed?	yes	no
Can you dress without help?	yes	no
Can you eat without help?	yes	no
Can you do your toilet without help?	yes	no

examination included the regions which were clinically examined In some cases roentgenologic examination was not done either because the joints were clinically normal and there was no history of joint haemorrhage or because the patients would not consent to such an examination When possible films were taken in two perpendicular planes Contractures and deformities especially of the knee and elbow joints sometimes made it impossible to place the patient in the proper position for antero-posterior and lateral views The films were checked in Malmö in cooperation with Lars Andren M D (Roentgen diagnostic Department Malmo General Hospital)

Interview Examination and Questionnaire

The functional ability of the patients was assessed with the aid of a questionnaire (Table 6) which contained specific questions concerning

their ability to walk, use of braces, activity of daily life, etc The same questionnaire was mailed to patients over 5 years of age who had failed to come for examination, or to their parents

CLASSIFICATION OF HAEMOPHILIC ARTHROPATHY

König (1892) distinguished between haemarthrosis, panarthritis, and the regressive stage and Key (1932) simplified this classification to comprise only two stages acute haemarthrosis and chronic arthritis None of these classifications were based on the degree of chronic arthropathy DePalma and Cotler (1956) and Jordan (1958) recognised four degrees of chronic haemophilic arthropathy These two classifications were largely the same with the exception that Jordan based his classification largely on the roentgenograph whereas DePalma and Cotler based their classification on a combination of the clinical and roentgenographic findings Largely the latter classification was used in this investigation

DePalma and Cotler distinguished four grades of arthropathy with grade 1 as the earliest form Joints belonging to this grade have no functional impairment, and classification is therefore made largely on the basis of very slight roentgenologic changes, such as some slight generalized decreased density of the bone ends , and some increased density of the capsular tissues These roentgenologic changes proved too subtle to serve as a basis for classification in the present investigation This was partly because the roentgenographs had been taken at different hospitals and not under standardized exposure conditions Therefore in this investigation only three grades of arthropathy were used corresponding largely to DePalma s grades 2 3 and 4 In order to facilitate direct comparison DePalma s terms were used

The classification was based on the findings listed in Table 7

Grade 2 Slightly reduced range of mobility not interfering with the function of the joint Increase in breadth of epiphyses subchondral cyst formation and/or increased trabeculation of the bone ends (Fig 2)

Grade 3 Reduced range of mobility interfering with the function of the joint Occurrence of valgus, varus subluxation or rotation deformity Roentgenologically demonstrable narrowing of the joint space osteophytes and/or incongruence of the joint surfaces Sclerosis of the ends of the bones (Fig 3)

Grade 4 Changes of the same type as grade 3 but more advanced *e g* ankylosis or marked loss of mobility pronounced deformity and severe sclerosis of the bone ends (Fig 4)

TABLE 7 Classification of haemophilic arthropathy

Grade	2	3	4
Range of motion	Slightly reduced No impairment of function	Reduced with impairment of function	Greatly reduced
Increased breadth of epiphyses	+	+	+
Subchondral cyst formation	+	+	+
Increased trabeculation	+	+	+
Narrowing of joint space	—	+	+
Osteophytes	—	+	+
Deformity (valgus varus subluxation rotation)	—	+	++
Incongruence of articular surfaces	—	+	++

CLASSIFICATION OF GENERAL DISABILITY

Classification according to disability was based on (a) clinical examination of the joints and (b) data from the questionnaires Patients not examined clinically were classified according to the notes made in the questionnaires The patients were informed that the questions referred to their condition when they were free from acute bleeding

Patients (a) without arthropathy of more than grade 2 and (b) without loss of function according to the questionnaire were said to be free from disability Three grades of disability were distinguished

1 *Mild general disability* (a) One or more joints with grade 3 arthropathy (b) impairment of one of the joint functions included in the questionnaire Can manage activity of daily life No need of orthopaedic appliances Can walk 1000 metres without stopping

2 *Marked general disability* (a) One or more joints with arthropathy of grade 3 or 4 (b) uses orthopaedic shoes splints and/or stick Can walk 100 metres but not 1 000 metres without stopping

3 *Severe general disability* (a) One or more joints with arthropathy of grade 3 or 4 (b) uses crutches wheelchair or is bedridden Cannot walk 100 metres without stopping Requires help to manage activity of daily life




a Left knee norm il




b Right knee grade 2

FIGURE 2 Knee joint grade 2 S P fam 215 7 years old




FIGURE 3 Knee joint grade 3 S W fam 28 28 years old




FIGURE 4 Knee joint grade 4 L L fam 36 33 years old

III Incidence of Musculo-skeletal Manifestations in Haemophilia A and B

ARTHROPATHY

Arthropathy in Haemophilia A and B

Ramgren (1962 a) was unable to show any difference between the symptomatology of haemophilia A and B Most of the patients in the present investigation were included in Ramgren's material but the incidence of arthropathy is analysed in greater detail

In the present material the distribution of the patients with haemophilia A according to degree of the disease and according to age was the same as that of the patients with haemophilia B (Tables 4 and 8) The two groups could therefore be compared regarding the incidence and degree of arthropathy (Table 9 and 10) No certain difference in either respect was found Patients with haemophilia A and those with haemophilia B were therefore pooled in the following analysis

Individual Joints (Table 11 and 12)

Hip

Of 157 patients 1 hip joint was involved in 11 and both in 1 Haemophilia was severe in 11 of these patients and moderate in 1 Hip arthropathy thus occurred in 1 out of every 9 patients with severe haemophilia and hardly ever in patients with moderate or mild haemophilia

Winston (1952) pointed out that the roentgenographic appearance of haemophilic arthropathy of the hip joint depends on whether the joint was initially affected before or after puberty In the former situation the appearance may resemble that seen in Legg Perthes disease and in the latter that of non specific coxarthrosis Peterson (1923) has described three cases with a Legg Perthes like affection of hip joint in haemophiliacs, and, like Caffey and Schlesinger (1940) he believed haemorrhage in the femoral capital epiphysis to be the cause of this appearance He pointed out that the appearance of haemophilic arthropathy of the hip joint may differ from Legg Perthes disease by presence of change also in the acetabulum

Most of the affected joints in the present material belonged to grade 3 Four hips belonged to grade 4 Of these, 3 were seen in patients below 20

Table 8 Age distribution of haemophilia A and B

Age in Years	Haemophilia A	Haemophilia B	A/B
0— 9	24	13	1 8
10—19	35	7	5 0
20—29	22	9	2 4
30—39	13	6	2 2
40—49	12	3	4 0
>49	8	5	1 6
Total	114	43	2 6

Table 9 Incidence of arthropathy in haemophilia A and B

Type of Haemophilia	A	B	A/B
Number of patients	114	43	2 6
Joints affected			
Hip	10	3	3 3
Knee	127	45	2 8
Ankle	68	28	2 4
Shoulder	21	7	3 0
Elbow	106	39	2 7
Wrist	17	3	5 7
Total	*349*	*125*	*2 8*

Table 10 Degree of arthropathy in haemophilia A and B

	Number of Joints affected		
Type of Haemophilia	A	*B*	*A/B*
Grade 2	104	27	3 9
Grade 3	170	70	2 4
Grade 4	75	22	2 7
Total	349	125	2 8

Table 11 *Incidence of arthropathy as a function of degree of haemophilia*

Degree of Haemophilia	Severe	Moderate	Mild	Total
Number of patients examined	95	38	24	157
Patients with arthropathy of				
hip	11(1)*	1	0	12(1)
knee	77(58)	21(13)	2(1)	100(72)
ankle	45(31)	12(7)	1	58(38)
shoulder	19(5)	2(2)	0	21(7)
elbow	66(49)	20(10)	0	86(59)
wrist	8(5)	5(2)	0	13(7)
Total number of joints affected	375	95	4	474

* Bracketed figures indicate number of bilateral cases

Table 12 Incidence of arthropathy as a function of age in severe and moderate haemophilia

Age in years		0—9		10—19		20—29		30—39		40—49		> 49		Total	
Haemophilia		Se	Mo	Se	Mo	Se	Mo	Se	Mo	Se	Mo	Se	Mo	Se	Mo
Number of patients examined		26	6	27	8	22	6	11	5	5	8	4	5	95	38
Number of joints affected															
Hip	grade 2			1		1								2	
	3			1		1		4				1		7	
	4			2	1			1						3	1
Knee	2	5	4	13	3	8	2	1			1		2	27	12
	3	6		20		27	4	9	6	6	4			68	14
	4	1		10		6		11		4	4	8	4	40	8
Ankle	2	4	1	7		16		7			7		1	34	9
	3	1		5		10	1	7		3	5	6	4	32	10
	4			3		2		2		1		2		10	
Shoulder	2			2		2		1		1			2	6	2
	3	1		1		2		4		1	2	3		12	2
	4					1		3		1		1		6	
Elbow	2	1	1	8	2	8	3	1		2	2		1	20	9
	3	5		19	2	23	1	13	4	2	5	5	4	67	16
	4			3		9		7		6	5	3		28	5
Wrist	2	1				4	1			1	1			6	2
	3							3		1	1	2	3	6	4
	4			1			1							1	1
Total	grade 2	11	6	31	5	39	6	10		4	11		6	95	34
	3	13		46	2	63	6	40	10	13	17	17	11	192	46
	4	1		19	1	18	1	24		12	9	14	4	88	15



FIGURE 5 Hip joint with Legg Perthes like roentgenogram U J fam 81 10 years old

years of age In one of these cases the appearance of the affected hip in which the change was detected when the patient was 8 years old resembled that seen in Legg Perthes disease (Fig 5) Advanced atypical destruction of the joint was demonstrated in the other 2 cases (Figs 6 and 7)

Knee

One hundred patients had knee joint arthropathy which was bilateral in 72 This condition was found in 4 cases out of every 5 patients with severe haemophilia in every other one with moderate haemophilia and only occasionally in patients with mild haemophilia In severe and moderate haemophilia the arthropathy when present was predominantly of grade 3 or 4 The joint changes were bilateral in three fourths of the patients with severe haemophilia and in half of those with moderate haemophilia

In severe haemophilia arthropathy of grades 3 and 4 was seen in 7 children out of 26 below 10 years and in 1 of 6 below 5 (L C S fam 37) In moderate haemophilia grade 3 arthropathy was never seen below the age of 20 and grade 4 never below 40 years Of patients with mild haemophilia only 3 knees were affected the most severe affection (grade 3) was seen in a 14 year old boy (K A fam 123) who had had a supracondylar fracture of the femur A 7 year old boy (R H fam 145) had bilateral changes of grade 2

There is general agreement that haemophilic arthropathy involves the knee more often than any other joint (Ghormley and Clegg 1948 Fonio



FIGURE 6 Hip joint grade 4 L G J fam 103 15 years old



FIGURE 7 Hip joint grade 4 A J fam 73 18 years old

and Buhler 1952, DePalma and Cotler 1956, Jordan 1958 Ramgren 1962 a and others) It might therefore be convenient briefly to describe the roentgenographic appearance of the most important changes seen in this joint The description applies also largely to the other joints The roentgenographic changes in haemophilic arthropathy have been described by several authors (Fonio and Buhler 1952, DePalma and Cotler 1956 Stiris 1958 Jordan 1958, Tengberg *et al* 1960 Holstein 1960 1961 Mosley 1963 and others) Favre Gilly (1964) published a roentgenologic investigation of the knee joints in 100 haemophiliacs aged 7 to 15 years

Changes in the epiphyses occur early the trabeculation is increased and the epiphyses are enlarged Cysts of varying size appear periarticularly Disturbed development of the epiphyses can lead to deformation of the femoral and tibial condyles The patella increases in size especially in thickness and its lower pole becomes squared off Erosion of the joint cartilage often occurs early *In later stages the cartilage undergoes destruction with* narrowing of the joint space and the formation of osteophytes

Developmental changes of the epiphyses and secondary degenerative *changes can together result in severe destruction of the joint Differences* in the rate of growth of the femoral condyles can cause valgus or varus deformity (Caffey and Schlesinger 1940) Webb and Dixon (1960) stated




FIGURE 8 Severe destruction of knee joints B B fam 72 15 years old

that collapse of the lateral tibial condyle due to osteoporosis can cause valgus deformity Jordan (1958) ascribed the outward rotation of the tibia often seen in haemophilic arthropathy to preponderance in growth of the medial femoral condyle DePalma and Cotler (1956) felt that contracture of the joint capsule, shortening and contracture of the hamstring muscles and of the iliotibial band may cause angulation and rotation deformity and also subluxation backwards of the tibia deAndrade *et al* (1965) showed that irritation of the knee joint capsule results in weakening of the quadriceps and hyperactivity of the hamstrings Such imbalance could readily produce flexion deformity and posterior subluxation of the tibia in haemophiliacs

In this investigation flexion contracture was the commonest cause of disability Valgus deformity and outward rotation of the leg were common but rarely severe enough to impair function In one case (B M fam 95) a supracondylar osteotomy was performed in a knee with 30 valgus deformity and instability (Ahlberg *et al* 1965) Varus deformity was uncommon One patient (B W fam 62) was operated upon with osteotomy of the tibia because of progressive varus deformity (p 62) Complete derangement of the knee joint could occur early (Fig 8) Bony ankylosis (Fig 15) was present in 4 patients all with severe haemophilia

Ankle

Fifty eight patients had changes in the talo crural and/or subtalar joints In 38 of them the lesions were bilateral The joint changes were found in

one half of the patients with severe haemophilia, in one third of those with moderate haemophilia and in only 1 of 24 with mild haemophilia Grade 4 arthropathy was seen only in patients above 15 and then always in association with severe haemophilia

In most of the cases the talo crural as well as the subtalar joints were involved Involvement of the talo crural joints alone was more common than affection of the subtalar joints alone In agreement with DePalma and Cotler (1956) flattening of the superior articular surface of the talus was a common observation here Complete collapse of the body of the talus as described by Crock (1962) was seen in one case bilaterally (Fig 9) Bony ankylosis of the ankle joints has been described by several authors (Fonio and Buhler 1952, DePalma and Cotler 1956, Jordan 1958) It was observed in one of the present cases (Fig 16)

Foot

In only 1 patient, a man with severe haemophilia (B S fam 46), were the small joints of the foot involved probably secondary to haemorrhage In both feet the tarsal, tarso metatarsal and metatarso phalangeal joints were severely affected and the toes were clawed The first metatarso phalangeal joint of one foot showed bony ankylosis

Affection of the small joints of the feet and toes thus seems to be rare in haemophilia No such changes are described in the compilations referred to previously (Table 1) Deformities caused by extraarticular haemorrhage are however known Thomas (1936) has described a case of peripheral gangrene with loss of toes following extensive haemorrhage of the leg Jordan (1958) reported one case of micromelia of the foot after haemorrhage in the central nervous system

Shoulder

Twenty one patients had shoulder joint changes, which were bilateral in 7 One fifth of the patients with severe haemophilia had shoulder affections usually grades 3 or 4 (Figs 10 and 11) Of 38 patients with moderate haemophilia 2 had affection of the shoulder joints In none of the 24 with mild haemophilia was the shoulder affected Involvement of the shoulder was rare in children and became progressively severe with advancing age of 53 patients with severe haemophilia and below 20 years the shoulder joints were affected in only 4 against 20 of 12 above 20 In 6 of the latter group the lesions were of grade 4





FIGURE 9 Collapse of the thalus B B fam 7? 15 years old



FIGURE 10 Shoulder joint grade 3 Y A fam 10 29 years old



FIGURE 11 Shoulder joint grade 4 L O W fam 48 37 years old

The literature contains little information on the incidence of shoulder arthropathy in haemophilia Thomas (1936) reported the presence of the condition in only 1 out of 98 haemophiliacs, Ghormley and Clegg (1948) in none of 76, Webb and Dixon (1960) in 4 of 42 Jordan (1958), however, found 16 cases of shoulder arthropathy among 56 haemophiliacs an incidence agreeing with that found in the present material

Fonio and Buhler (1952) have described atrophy of the head of the humerus in 2 cases The youngest patient with shoulder arthropathy in the present investigation, a boy of 7 (R B fam 59), had restricted range of motion muscular atrophy and roentgenologic evidence of atrophy of the head of humerus (Fig 12) There was no evidence of any neurogenic cause of this condition

Elbow

The elbow was affected in 86 patients including 59 in whom the changes were bilateral Two thirds of the patients with severe haemophilia were affected half of them bilaterally Of those with moderate haemophilia half were affected a quarter of them bilaterally None of the patients with mild haemophilia were affected Grade 4 arthropathy was seen in severe haemophilia in patients as young as 10—14 years and became progressively more common with advancing age Grade 4 arthropathy was never observed before age of 40 in patients with moderate haemophilia

In patients with grade 3 or 4 extension flexion as well as pronation supination was as a rule impaired

Enlargement of the head of the radius was observed as early as 1897 by Shaw i e 2 years after Roentgen s discovery of the x ray It was often seen in this investigation (Fig 13) Knobbiness of the distal epiphysis of humerus sometimes with valgus deformity (Klason 1921 Caffey and Schlesinger 1940) and deepening of the ulnar and radial incisuras and fossa olecrani (Fonio and Buhler 1952) are other typical changes Bony ankylosis was not seen

Wrist

Thirteen patients had wrist joint arthropathy, which was bilateral in 7 The condition was equally common in moderate and severe haemophilia and was seen in about one tenth of these patients Only 2 patients were below 20 years It was not seen in patients with mild haemophilia

Newcomber (1939) described one case and Webb and Dixon (1960) two with deformity of the distal end of the ulna which they felt was due to





a Right shoulder atrophy b Left shoulder normal

FIGURE 12 Atrophy of head of humerus R.B fam 59 8 years old





FIGURE 13 Elbow joint grade 4 G F fam 68 34 years old

haemorrhage The only 2 cases of grade 4 observed here had a rather similar radiographic appearance the distal end of the ulna had bent dorsally causing complete luxation of the carpo ulnar joint (Figs 14 a and b)

Hand

Of 157 patients, only 4, all with severe haemophilia, had lesions of the small joints of the hands or fingers In all 4 the range of motion of at least one joint was impaired, probably from articular haemorrhage None of these lesions caused any significant restriction of hand function

In haemophilia restriction of hand and finger function caused by haemorrhage into joints of the hand and fingers seems to be rare Thomas (1936) states that finger bleeding occurred in 15 of his 98 cases but with permanent joint changes in only 2 Fonio and Buhler (1952) described deformity of the metacarpals However, impairment of hand or finger function following haemorrhage in the arm is important (p 37)

Bony Ankylosis

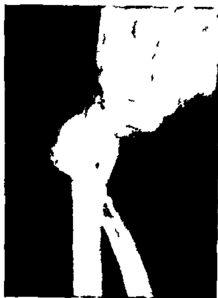
Bony ankylosis is rare in haemophilic arthropathy Key (1932) stated that bony ankylosis 'apparently does not occur and DePalma and Cotler (1956) Jordan (1958), Stiris (1958), Holstein (1960) and Tengberg *et al* (1960) have described ankylosis in all together 5 knee joints and 4 ankle or subtalar joints

Astrup and Sjolin (1958) feel that protracted joint bleedings in haemophiliacs can give rise to increased formation of clots which are difficult to be dissolved completely by the available amount of fibrinolytic agents Lack (1959) demonstrated a decreased fibrinolytic activity in tuberculous arthritis so that fibrin accumulates on joint surfaces, which may result in pannus formation and fibrous ankylosis In septic arthritis however, there is increased fibrinolytic activity and frequently rapid destruction of the cartilage with consequent bony ankylosis The deficiency of fibrinolytic activity in the joints in haemophiliacs may thus help to explain why bony ankylosis is rare in such patients

In the present investigation 6 joints with bony ankylosis were observed in 5 patients (Table 13) all of whom had severe haemophilia Those 4 who had ankylotic knee or ankle joints (Figs 15 and 16) believed that the joint had stiffened after treatment with traction immobilization in plaster, joint puncture or other therapeutic measures In one case (B M fam 95) bony ankylosis of the knee developed after surgical correction of a valgus deformity




a O P fam 27 22 years old




b G E fam 61 18 years old

FIGURE 14 Luxation of carpo-ulnar joint.

TABLE 13 Bony ankylosis in haemophilic arthropathy

	Family No	Haemophilia	Initials	Year of Birth	Joint	Comments
1	18	A Severe	N G W	1930	Knee	Stiff after manipulation of flexion contracture under anaesthesia at 18 years
2	18	A Severe	N G W	1930	Ankle	Stiff after aspiration of haemarthrosis at 18 years
3	31	B Severe	K P	1932	Knee	Stiff after repeated aspiration of haemarthrosis at 20 years
4	46	A Severe	B S	1921	Metatarso phalangeal joint first toe	
5	56	B Severe	A J	1925	Knee	Stiff after treatment in cast for 6 months at 8 years
6	95	A Severe	B M	1946	Knee	Stiff after wedge osteotomy of valgus deformity at 16 years



FIGURE 15 Ankylosis of knee joint N G W fam 18 33 years old



FIGURE 16 Ankylosis of ankle joint N G W fam 18 33 years old

JOINT SCORE
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
1 2 3 4 5 6 7 8 9 10 20 25
PLASMA CONCENTRATION OF AHF OR B FACTOR (/)

FIGURE 17 Arthropathy as a function of AHF and B factor levels

Incidence of Arthropathy of Various Joints

In both severe and moderate haemophilia arthropathy was most frequent and severe in knee elbow and ankle joints in the order given (Table 11 and 12) Shoulder wrist and hip joints were considerably less frequently involved Involvement of the joints of hands and feet was rare in severe haemophilia and was not observed in moderate haemophilia

Arthropathy as a Function of Degree of Haemophilia

The frequency of arthropathy increased with the severity of the haemophilia (Table 11 and 12) In patients with mild haemophilia only 4 joints were involved (two grade 2 and two grade 3) In patients with severe haemophilia arthropathy of grade 4 was more than twice as common as in those with moderate haemophilia and grade 3 was twice as common while the difference in frequency of lesions of grade 2 was negligible The age distribution is not taken into account here Since the proportion of patients in the higher age classes in the group with moderate haemophilia was larger than in severe haemophilia the true differences were more marked than those suggested by these numbers

The relation between the levels of AHF and of B-factor in the plasma and the grade of arthropathy in adult haemophiliacs is shown in Fig 17 where each point represents a haemophiliac of 20 years or more The total

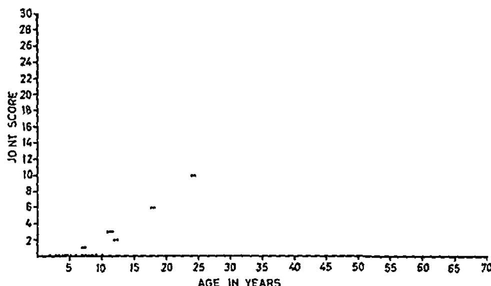


FIGURE 18 Arthropathy as a function of age Severe haemophilia

degree of arthropathy in each of the patients was calculated by giving the various degrees of arthropathy 1 to 3 points and then adding the points allotted to the joints affected This value reflects the severity of the joint disease from a pathological anatomical point of view rather than from a functional standpoint The value obtained was called the joint score These values were plotted against the plasma levels of the AHF and of the B factor Owing to the error of the method in the evaluation of these factors (page 11) values below 1 % could not be determined with exactitude and were therefore plotted as 0 5 %

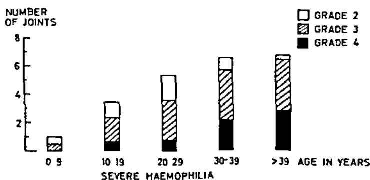
The joint score decreased with increasing values of the respective coagulation factors Of the patients with a coagulation factor content above 2 % only 2 had joint symptoms a 49 years old man with an AHF content of 3 % (A M, fam 132) had a joint score of 7 and a 26 years old man with 7 % (I T fam 135) had a joint score of 2

Chronic joint changes in patients with a coagulation factor content above 2 –3 % thus prove rare

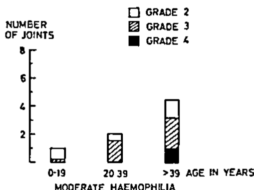
Arthropathy as a Function of Age

The joint scores of the patients with severe haemophilia were plotted against age (Fig 18) Statistical treatment of the data showed that in

[1] Data treated statistically under supervision of Professor C E Quensel Institute of Statistics University of Lund



a Severe haemophilia



b Moderate haemophilia

FIGURE 19 Mean number of affected joints per patient in various age-classes

patients above 10 years the score increased with age at a fairly constant rate of 0 4 units per year

For patients with a content of 1—3 % the rate of increase was about half of that for patients with a coagulation factor content of less than 1 %

The patients with severe haemophilia were distributed among 10 year age classes and the mean number of joints affected (grades 2—4) per patient in each of the age classes was calculated (Fig 19 a)

The total number of joints affected was found to increase with patients ages up to 20 years after which the increase in the number of joints involved was small (5 4 joints in the 20—29 year class, 6 6 in the 30—39 year class and 6 8 in patients above 39 years) but the severity of the lesions continued to increase

TABLE 14 Neurogenic lesions in haemophilia

	Family No	Haemo philia	Initials	Year of Birth	Site of Haemorrhage	Functional Defec
1	8	B Severe	K E C	1909	Elbow Region	Paresis of ulnar and r nerves
2	68	A Severe	G F	1930	Gluteal Region	Paresis of sciatic ner
3	112	B Severe	S J	1943	Thigh	Drop foot
4	184	A Moderate	T B	1958	Spinal Cord	Paraplegia

The number of patients with moderate haemophilia was small and there fore the patients were distributed only among 20 year age classes (Fig 19 b) Here too, the lesions tended to advance with age The changes did not appear so early as in the group with severe haemophilia

The haemophilic joint changes thus increase with age The rate of in crease after 10 years of age is largely constant in each grade of haemophilia but it is higher in severe than in milder degrees of haemophilia

EXTRA-ARTICULAR LESIONS

Neurogenic

Four patients were found to have permanent neurogenic joint dysfunction (Table 14) one had developed paraplegia following haematomyelia, one had paresis of the ulnar and radial nerves after haemorrhage in the elbow region two had paresis of the foot following haemorrhage in the gluteal region or fracture of the femur The lesions were 4—7 years old, so that they could be regarded as constant

Aggeler and Lucia (1944) and Silverstein (1964) described neurogenic complications in haemophilia following haemorrhage affecting the ulnar medial peroneal sciatic femoral and facial nerves Tallroth (1939) de scribed a case of paralysis of the quadriceps musculature following haemor rhage in the iliopsoas muscle with injury to the femoral nerve Haemor rhage in the central nervous system may, though rarely cause temporary paresis (Aggeler and Lucia 1944) Jordan (1958) described a case of micromelia of the foot after bleeding in the central nervous system The observations reported here confirm earlier impressions that neurogenic causes of chronic musculo-skeletal dysfunction are rare in haemophilia

Table 15 Myogenic lesions in haemophilia

	Family No	Haemophilia	Initials	Year of Birth	Site of Haemorrhage	Functional Defect
1	14	B Moderate	B G	1922	Iliopsoas Muscle	Flexion contracture of the hip
2	34	A Severe	O L	1938	Calf Muscle	Equinus deformity of the ankle
3	42	A Severe	B R	1924	Volar Muscles of Lower Arm	Contracture of fingers
4	46	A Severe	B S	1921	Calf Muscle	Equinus deformity of the ankle
5	61	B Severe	G E	1944	Wrist and Hand	Contracture of fingers
6	72	A Severe	L B	1948	Calf Muscle	Equinus deformity of the ankle
7	123	A Mild	K A	1949	Tigh Muscles	Contracture of the knee
8	161	A Moderate	B M	1938	Calf Muscle	Equinus deformity of the ankle
9	183	B Severe	B N	1947	Calf Muscle	Equinus deformity of the ankle

Myogenic

Nine patients were found to have myogenic joint dysfunction (Table 15) five had equinus deformity of the ankle joint following haemorrhage in the calf one had flexion contracture of the hip following haemorrhage in the iliopsoas muscle one a contracture of the knee after a femoral fracture and two had flexion contracture of the fingers following haemorrhage in the musculature of the lower arm

Intramuscular haemorrhage may cause fibrosis and muscle contracture Field (1963) described 3 cases of equinus deformity of the ankle joint in whom achillotenotomy and capsulotomy were performed under protection of human fibrinogen rich in AHF Hip joint deformity following haemorrhage in the iliopsoas muscle has been described by Birch (1932) Tallroth (1939) Davidson *et al* (1949)

Several authors have reported dysfunction following haemorrhage in the lower arm causing Volkmann s contracture (Lord 1926 Thomas 1936 Hill and Brooks 1936 Newcomber 1939) This complication might have occurred in one case here (B R fam 42) but the lesion may also have been caused merely by organization of an intramuscular haematoma and need not have been related to ischaemic necrosis

TABLE 17 Sites of pseudotumours in haemophilia

Site	No of Cases
Femur	20
Ilium	13
Thumb	2
Tibia	2
Pubis	1
Olecranon	1
Humerus	1
Metatarsal	1
Total	41

This table is based on Abell and Bailey (1960) Nelson and Mitchell (1962) Hall *et al* (1962) Caen *et al* (1964) Lewis *et al* (1965) Jones (1965) and Table 16 reported here

lesion A review of cases described to date is given according to localization in Table 17 from which it is clear that the commonest sites were the femur and ilium

The roentgenologic appearance of haemophilic pseudotumours shows evidence of mingled areas of bone destruction and new bone formation It has been described by Becker (1942) and Echtenacht (1943) and others The appearance is sometimes difficult to distinguish from that of osteogenic sarcoma (Becker 1942 Nelson and Mitchell 1962, and others)

Histologic examination of material obtained at biopsy or autopsy has shown that the lesions consist of organizing haematoma in which new bone is being formed (Ghormley and Clegg 1948 Silber and Christensen 1959, Nelson and Mitchell 1962)

It is clear from the literature that the mortality from diagnostic and therapeutic surgery of pseudotumours has been high Only when there is strong reason to suspect that the changes are malignant or if the tumour continues to grow despite conservative treatment including infusion of concentrated AHF or B factor preparations should operation be considered and if decided upon, it should always be done under cover of adequate replacement therapy

IV Disability due to Musculo-skeletal Manifestations in Haemophilia

In a medicosocial study of haemophiliacs in Sweden in 1962 Ramgren reported *inter alia* the school attendance occupation and working capacity of the patients The present investigation is concerned with the general condition of haemophiliacs in Sweden from an orthopaedic point of view

The degree of disability was assessed on the basis of the clinical findings and/or the questionnaires (p 15) Two hundred and forty two patients were classified in this respect (Table 18) It is clear from Table 4 that most of those studied only by questionnaire had haemophilia of mild type The age distribution of the patients according to the severity of haemophilia was the same in the group studied by questionnaires as in the group studied clinically The two groups were therefore pooled The data refer to periods without acute bleeding

DISABILITY RELATED TO AGE AND DEGREE OF HAEMOPHILIA

In patients with *severe haemophilia* (Table 19) the degree of disability increased markedly with age up to 15 years About half of the patients below 15 years were free from any disability against only 3 patients above this age (all in age class 15—19 years) The variation of the degree of disability with age is clear from Fig 23 where the various degrees are allotted points (0—3) and the mean scores of the various age classes are given The mean scores increased markedly up to the 15 years after which no further increase could be demonstrated with certainty

Ramgren (1962 b) found the life expectancy of severe haemophiliacs to be one third of that of the normal male population The ratio between the observed and the expected number of deaths among severe haemophiliacs during the years 1958—1962 was 1 10 If the mortality varies with the degree of disability *i e* if those with a higher degree of disability die earlier it would help to explain why no increase in the degree of disability could be demonstrated in patients above 15—20 years

TABLE 18 Degree of disability as a function of severity of haemophilia

Degree of haemophilia	Severe	Moderate	Mild	Total
Number of patients	102	59	81	242
Degree of disability				
None	20	32	78	130
Mild	24	15	2	41
Marked	40	8	1	49
Severe	18	4		22

TABLE 19 General disability in severe haemophilia as a function of age

Age	Total	Examined	Degree of Disability			
			0	1	2	3
0— 4	13	6	5	1		
5— 9	22	20	10	5	3	2
10—14	11	11	2	2	3	4
15—19	21	20	3	4	7	6
20—24	13	12		7	3	2
25—29	13	12		2	9	1
30—34	5	5		1	3	1
35—39	6	6		1	5	
40—44	3	2			2	
45—49	3	3		1	2	
50—54	2	2			1	1
> 54	4	3			2	1
Total	116	102	20	24	40	18

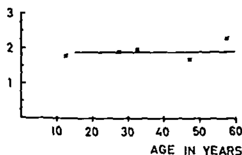


FIGURE 23 Mean degree of disability in different age classes in severe haemophilia

TABLE 20 General disability in moderate haemophilia as a function af age

Age	Total	Examined	Degree of Disability			
			0	1	2	3
0— 4	3	1	1			
5— 9	6	6	3	2	1	
10—14	5	5	2	2		1
15—19	7	6	3	3		
20—24	9	9	4	2	3	
25—29	4	3	3			
30—34	4	4	3	1		
35—39	5	5	2	2	1	
40—44	5	4	1		2	1
45—49	5	5	3	1		1
50—54	4	4	2		1	1
> 54	8	7	5	2		
Total	65	59	32	15	8	4

Of the 59 patients with *moderate haemophilia* (Table 20) 32 were free from any disability while 12 were markedly or severely disabled Observations made in the patients with moderate haemophilia suggested that the degree of disability tended to increase with advancing age only 2 of 18 patients below 20 being markedly or severely disabled against 6 of 20 above 40 The overmortality among the patients with moderate haemophilia was not high enough to have any substantial effect on the results (The ratio between the expected and observed number of deaths was 1 2) The series was however too small and too heterogenous from a point of view of coagulation defect to warrant any conclusion about the variation of the degree of disability with age

Of 81 patients with *mild haemophilia* (Table 21) only 3 were disabled 1 markedly and 2 mildly In the markedly disabled patient (K S fam 203) the disability was due to impaired function of the knee after a severe blow In one of the mildly disabled patients (K A fam 123) the disability was due to fracture of the femur In the other patient (L T, fam 135) function of one of the ankles was impaired without any known preceding trauma

In mild haemophilia then disability is rare and when it does occur it may be due to trauma

TABLE 18 Degree of disability as a function of severity of haemophilia

Degree of haemophilia	Severe	Moderate	Mild	Total
Number of patients	102	59	81	242
Degree of disability				
None	20	32	78	130
Mild	24	15	2	41
Marked	40	8	1	49
Severe	18	4		22

TABLE 19 General disability in severe haemophilia as a function of age

Age	Total	Examined	Degree of Disability			
			0	1	2	3
0—4	13	6	5	1		
5—9	22	20	10	5	3	2
10—14	11	11	2	2	3	4
15—19	21	20	3	4	7	6
20—24	13	12		7	3	2
25—29	13	12		2	9	1
30—34	5	5		1	3	1
35—39	6	6		1	5	
40—44	3	2			2	
45—49	3	3		1	2	
50—54	2	2			1	1
> 54	4	3			2	1
Total	116	102	20	24	40	18

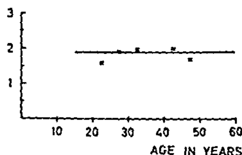


FIGURE 23 Mean degree of disability in different age classes in severe haemophilia

USE OF ORTHOPAEDIC APPLIANCFS

Only 1 of the 242 patients was bedridden and 8 had to use a wheelchair All 9 had severe haemophilia Four patients used crutches and 12 used one or two sticks Thirteen patients wore orthopaedic braces splints or shoes (Table 22)

ACTIVITY OF DAILY LIFE

Only 5 patients (1 bedridden and 3 bound to wheelchair) could not manage their daily life (dressing eating toilet) without help because of disability due to the musculo skeletal system

V Correction of Muskulo-skeletal Deformities in Haemophilia

INTRODUCTION

As shown in Chapters III and IV, joint contractures and deformities are common in haemophiliacs and are often disabling Formerly the risk of haemorrhage severely limited the possibilities of active treatment in haemophilia It is generally accepted that replacement therapy is necessary in association with surgical intervention on haemophiliacs Even continuous traction and physiotherapy to correct the joint deformities carry a risk of haemorrhagic complications liable to prolong treatment and jeopardize the results Blood and plasma were the preparations formerly used in the treatment of haemophilia A and B But it is now known that these are not sufficient to control the bleeding in certain situations Experience has shown that if haemostasis in association with surgical intervention is to be satisfactory, the plasma AHF or B factor must be at least 30—70 % of normal during the first 24 hours after the operation and 20—40 % during the rest of the healing period (Brinkhous *et al* 1956 Biggs and Macfarlane 1962, Nilsson *et al* 1962 and others) Elevation of the AHF level from 0 to 35 % in an adult requires infusion of at least 3 litres of fresh blood or 1 1/2 litres of fresh plasma AHF is rapidly consumed Biggs (1963) found a half time of about 14 hours, for which reason the infusion must be repeated often This requires the use of concentrated preparations

During the second world war Cohn *et al* (1946) devised a method for fractionation of plasma (method 6) The various fractions were tested for antihaemophilic activity Such activity was demonstrated mainly in fraction I But it was found to vary probably because of contamination with thromboplastin, prothrombin and plasmin The fraction was therefore not widely used clinically

Of greater practical importance was a fibrinogen fraction prepared by Kekwick *et al* (1946 1957) They used a fractionation technique with ether The preparation had an AHF activity of 20—25 times that of human plasma per mg protein It was used clinically but side effects were reported

Concentrated AHF has been prepared from bovine and pig blood (Bid

well 1955 a 1955 b) Treatment of patients with haemophilia A with this fraction has been reported by the Oxford group (Biggs 1960) Good results have been achieved though the side effects and the antigenic properties considerably limit the range of indications for the preparation Macfarlane *et al* (1957) claim that the preparation should only be used in life-threatening situations

In 1956 Blomback and Blombäck described a method for purifying fibrinogen from Cohn's fraction I by treatment with a glycine solution containing ethanol and citrate With this method they obtained a fraction I—0 in which 85—90 % of the protein consisted of fibrinogen Fraction I—0 proved practically free from plasmin and prothrombin and was therefore stable It has been used in Sweden since 1956 in the treatment of haemophilia A (Blomback and Blomback 1956 Blombäck and Nilsson 1958 Blomback *et al* 1960 Nilsson *et al* 1962, Nilsson 1965) This fraction proved successfully to control bleeding even in association with major operations and not to cause any serious side-effects Preparations largely analogous to fraction I—0 have since been used by other authors in the treatment of haemophilia A (McMillan *et al* 1961 Newcomb and Watson 1963)

Later concentrated preparations of B factor also became available Thus Soulier (1961) prepared a haemophilia B concentrate fraction P P S B from human serum and Biggs *et al* (1961) a similar concentrate from human plasma The preparations have proved clinically useful

METHODS

Human fraction I—0 (AHF concentrate)

Human fraction I—0 containing AHF was prepared at the Chemistry Department II Karolinska Institutet Stockholm by the glycine method of Blomback and Blomback (1956) One dose of this fraction is prepared from 1400 to 1600 ml of plasma and contains about 3 g of protein As a rule half a dose or a whole dose is given at a time A half dose of fraction I—0 is dissolved in 100 ml of isotonic saline The preparation has an activity of 5—8 times that of normal plasma

Fraction P P S B a concentrate of human haemophilia B factor

Fraction P P S B—10 (lot 206) was obtained from Centre National de Transfusion Sanguine by courtesy of Professor J P Soulier, Dr [illegible] and Dr D Menache The fraction is prepared according to the [illegible]

reported by Soulier (1961) This method consists of adsorption of human plasma to $Ca_3(PO_4)_2$, after which this precipitate is eluted with 0 18 M sodium citrate solution and concentrated by precipitation with 25 % ethanol at −5° C and pH 5 2 The fraction is sterilized by filtration through Millipore filter after stabilisation by addition of a small amount of heparin and then freeze dried The fraction contains prothrombin, factor VII, factor X and factor IX Each bottle contained about 260 mg of freeze dried protein, and an isotonic solution was prepared by dissolving the content of one bottle in 10 ml of distilled water According to Dr D Menache, *the activity of factor IX in vitro in the lot obtained was 30 times* more than the equivalent volume of plasma, *i e* a bottle of 10 ml was equivalent to 300 ml of plasma

Coagulation tests During treatment the AHF and B factor, respectively were determined according to the method described on page 11




FIGURE 24 Case 4 L E H fam 213 10 years old Left knee before treatment

CASE REPORTS AND RESULTS

Eleven patients were treated on all together 13 occasions All of them had severe haemophilia (type A in 9 and type B in 2) Nine were treated with continuous traction and 4 with surgical operations (Table 23) Three (L W L R C and B M) have been reported previously (Ahlberg *et al* 1965) The family histories symptoms and coagulation data in all of the 11 cases have been described elsewhere (Nilsson *et al* 1961 Ramgren 1962 a and Addendum p 99)

Case 4 L E H male born in 1953 severe haemophilia A (family 213) Since the age of 2 years he had had repeated spell of bleeding into the joints of the knees ankles and elbows A blow against the left knee in 1961 was followed by heavy bleeding into the joint Since then he has had contracture of the knee joint and walking difficulties Owing to an extension defect of the left knee he had to walk on his forefoot In August 1963 he was admitted for treatment of the deformity of the left knee joint

On admission the left knee was found to be increased in breadth there was about 15° valgus deformity and slight outward rotation of the lower leg and an extension defect of 30 Range of motion 50° (150°—100°) Atrophy of the thigh The mobility of the left elbow was reduced (150°—60°) All the other joints examined appeared largely normal Roentgen examination of the left knee revealed typical changes with increased breadth of the tibial and femoral condyles deformation of the patella coarse trabeculation and erosion of the articular surfaces (Fig 24)

Treatment of the left knee joint

On August 9 continuous traction with a weight of ? kg was started After 10 days extension the defect had diminished from 30° to 20° and treatment was continued

TABLE 75 Correction of deformities in severe haemophilia

Case No	Family No	Initials	Age in years at treatment	Type of haemophilia	Status before treatment	Orthopaedic treatment	Substitution therapy	Hospitalisation in weeks	Status on discharge	Complications
1	171	L W	6	A	Rt knee 110—60° Uses crutches	Traction Extension brace	AHF 0 5 dose/wk Total 8 doses	14	Rt knee 170—150° Walks without crutches	—
2	71	I R C	11	A	Lt knee 110—100° Uses crutches	Traction Extension brace	AHF 0 5 dose/wk Total 2 5 doses	10	Lt knee 170—160° Walks without crutches	—
3	95	B M	16	A	Rt knee 140—100° Valgus deformity Uses wheelchair	1) Traction Extension brace	AHF 0 5 dose/wk Total 4 5 doses	10	Rt knee 180—75° Valgus 30° Walks with knee brace	—
						2) Supracondylar Osteotomy	AHF total 30 5 doses	12	Rt knee ankylotic at 175° valgus 5° walks without brace	*Minor haemorrhage in the operation region on 18th postop day*
4	213	L E H	10	A	Lt knee 150—100° Valgus 15° Walks with severe limp	Traction Extension brace	AHF 0 5 dose/wk Total 2 doses	4	Lt knee 170—110° Valgus unchanged Walks well	—
5	106	S O J	8	A	Lt knee 120—110° Uses crutches	Traction	AHF 0 5 dose×2	8	Lt knee 180—180° Walks without crutches	Hemarthrosis lt knee during treatment
6	28	S W	28	A	Lt knee 160—135° pain at motion locking repeated haemorrhage unable to work	Arthrotomy with excision of osteophytes and extension	AHF total 16 doses	6	Lt knee 180—90° no pain at motion	—

7	100	B A	16	B	Lt knee 90—60° Uses crutches	Traction Extension brace	450 ml plasma×11		Lt knee 145—70° Walks without crutches Uses stick occasionally	—
8	72	L B	16	A	Rt knee 130—70° Equinus 120° Uses wheelchair	Traction Extension brace	AHF 1 dose+ 450 ml plasma×5	6	Rt knee 175—60° Equinus unchanged Walks well	—
9	183	B A	18	B	Lt knee 160—70° Equinus 110° Walks with difficulty	1) Traction Extension brace	450 ml plasma×6	4	Lt knee 175—70° Equinus unchanged	—
						2) Lengthening of Achilles tendon and posterior capsulotomy	420 ml fraction PPSB+4700 ml plasma	8	Foot in normal position Walks well	—
10	169	R H	12	A	Lt knee 145—90° Walks with stick	Traction Extension brace	AHF 0.5 dose+ 400—625 ml plasma×5	9	Lt knee 175—60° Walks better but uses knee brace because of weak muscles	—
11	67	B W	23	A	Rt knee 155—90° Varus deformity 25° Walks with difficulty	Wedge osteotomy on the proximal tibia	AHF total 54 doses	18	Rt knee in good position 180—150°	Bleeding in the operation region 2 days and 8 weeks postop Pneumonia on the 5th postop day

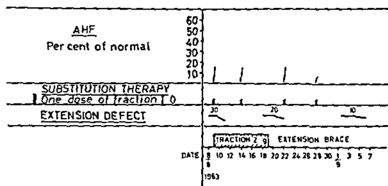


FIGURE 25 Case 4 I E H fam 213 Treatment and course

with an extension brace Walking exercises were started After a further 2 weeks the defect had decreased to 10°

On September 6 when the patient left hospital he could walk with less difficulty he could step on the entire foot and he limped only slightly Range of mobility 170°—110° He was instructed to use the extension brace at night Active movement exercises At follow up in February 1964 and July 1965 walking ability was still good Mobility of the knee joint 170 —80° and improved musculature of the thigh

AHF dosage and plasma AHF levels (Fig 25)

Before traction treatment was started the patient was given half a dose of fraction I—0 *i e* 100 ml This dose was repeated three times at intervals of one week *i e* all together 4 half doses of fraction I—0 Before the first injection the patient had an AHF level of 0 1 % of normal Immediately after administration of half a dose of fraction I—0 the AHF increased to between 14 and 18 % After a week the AHF was 1 % During his stay in hospital he had no bleeding into the left knee joint or other bleeding symptoms

Case 5 S O J male born in 1955 severe haemophilia A (family 106) In 1959 he had bleeding into the left elbow joint and in 1961 into the left knee joint In the beginning of December 1962 he again had bleeding into the left knee joint after wrenching of the knee The symptoms persisted after 2 weeks rest at home Medical advice was then sought and the patient was admitted to hospital for AHF therapy Owing to persistence of the extension defect of the knee joint on January 15 1963 6 weeks after the trauma the patient was transferred to the Department of Orthopaedic surgery Malmo general hospital

On admission Moderate exudate in the left knee joint Extension defect of 60° Range of motion 10° (120°—110°) Roentgen examination revealed broadening of the femoral condyles coarse trabeculation of the bones and erosion of the articular surfaces (Fig 26) The mobility of the elbow joint was somewhat reduced Other joint examined appeared normal

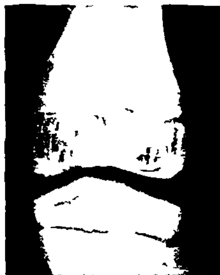




Figure 26 Case 5 S O J fam 106 8 years old Left knee before treatment

Treatment of the left knee joint Continuous traction with a weight of 2 kg was started on January 15 1963 After one week s treatment the extension defect was reduced to 20 (mobility 160°—135°) After a further week s treatment the weight was increased to 3 kg and used for one week On February 8 1963 the extension defect was 10° Mobility 50 (170°—120°) Traction was discontinued and walking exercises were started *On February 18 1963 the patient showed symptoms of fresh bleeding into the left knee joint with pain swelling and extension defect* After 2 days bedrest extension with a weight of 2 kg was re assumed and continued for 5 days The knee was fully extended but the range of flexion was only 10 He left hospital on March 8 1963 The range of movement of the knee joint was then 180°—170°

At re examination in January 1964 and March 1965 his condition was largely unchanged with the knee extended but with a range of flexion of only 10°

AHF dosage and plasma AHF levels (Fig 27)

During the period December 14 and January 15 the patient received 8 half doses of fraction I—0 because of an acute haemarthrosis in the left knee joint In connection with the subsequent traction treatment he received only 2 half doses of fraction I—0 owing to shortness of the preparation The preparations were given on January 22 and on March 3 AHF determinations were only performed before the administrations and the AHF level in these samples ranged between 0 1 and 1 and was never higher than 1 %

Case 6 S W male born in 1936 severe haemophilia A (family 28) Ever since *childhood he had had repeated bleeding into the knee joints ankles right elbow* and wrists Wrenching of the knee in 1962 was followed by a severe haemarthrosis Since then he has often had effusions and pseudo locking of the knee The symptoms gradually progressed and from 1963 he was unable to work (draughtsman) In

TRACTION OF LEFT KNEE JOINT
S O J (Fam 106) 8 yrs (weight 26 kg)

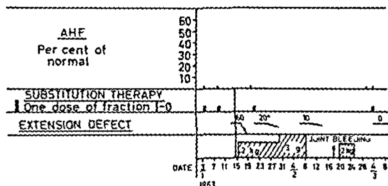


Figure 27 Case 5 S O J fam 106 Treatment and course

1964 he was admitted to hospital for investigation and treatment of increasing symptoms and disability

On admission No exudate in the knee Range of mobility 160°—135° Pain on movement Tenderness to palpation over the medial aspect of the joint Roentgen examination showed arthropathy of haemophilia with severe destruction of the joint cartilage especially medially and marginal spurring Coarse trabeculation and subchondral cyst formation (Fig 3)

Treatment of the left knee joint

Owing to the protracted and severe symptoms arthrotomy was considered indicated because of suspected medial meniscus rupture or loose body The operation was performed on March 17 1964 with a parapatellar incision medially The synovia was thick red brown The joint contained old liquid blood and some clots The joint was markedly destroyed Massive intraarticular adhesions made inspection difficult No rupture of the medial meniscus The medial femoral condyle showed abundant marginal osteophytes These were chiseled off and the knee joint was fully extended Partial synovectomy was done Moderate bleeding during the operation Bleeding vessels were ligated with fine silk Pressure bandages were used The postoperative course was smooth No haemorrhage

The patient left hospital one month after the operation He then walked with a stick No longer any tenderness or pain over the medial aspect of the joint No symptoms of pseudolocking The range of motion had improved to 180°—90° At after-examination in September 1964 the patient walked without a stick He had had no symptoms of pseudolocking Mobility 180°—75°

AHF dosage and plasma AHF levels (Fig 28)

The patient received 2 doses of fraction I—0 immediately before the operation one dose at the end of the operation and one dose 7 hours after the operation During the night he received two transfusions of fresh blood On the first postoperative day he received two and a half doses of fraction I—0 on the second postoperative day 2 doses of fraction I—0 and 600 ml of fresh plasma on the third one and a half doses

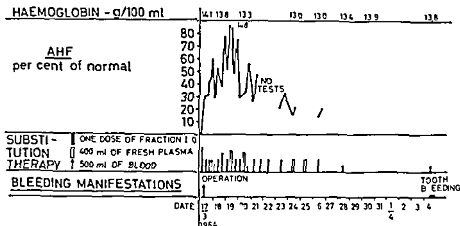


Figure 28 Case 6 S W fam 28 Treatment and course

of fraction I—0 and 600 ml of fresh plasma and on the fourth day 2 doses of fraction I—0 On each of the following 5 days he received one dose of fraction I—0 or 400 ml of fresh plasma Two further half doses of fraction I—0 were given in the postoperative course The AHF level was 30—60 % during and after the operation and between 30 and 148 % during the first four postoperative days and between 15 and 30 % during the following 5 days The patient received all together 16 doses of fraction I—0 2000 ml of fresh plasma and 2 blood transfusions

Case 7 B A male born 1948 severe haemophilia B (family 100) Ever since the *age of 2 years he had had recurrent bleedings into the joints usually the knees* less often the ankles and elbows In the autumn of 1962 he had severe haemorrhage into the left knee joint with increasing reduction of the range of extension of the joint He had to use a stick or crutches In April 1964 he was referred to Malmo general hospital for treatment of the defective extension

On admission The left knee was increased in breadth and deformed No exudate was demonstrable in the joint The knee was flexed 90° and there was a subluxation backward of *the tibia Range of motion* 90°—60° The flexor tendons of the knee joint stood out like tense strings (Fig 29 a) Roentgen examination revealed broadening of the femoral condyles deformation of the patella and decalcification (Fig 30) The right knee and the right elbow showed mild changes of the type seen in haemophilic arthropathy Other joints examined were of normal appearance The patient used crutches

Treatment of the left knee joint On April 23 1964 treatment with traction was started with a weight of 3 kg *Traction was interrupted about an hour a day for* leg exercises After 2 weeks the extension defect had diminished from 90° to 50° with preservation of flexion The weight was increased to 4 kg and treatment was continued for a further 4 weeks The mobility of the leg was then 145°—70° The





a Left leg before treatment

b Left leg after treatment

FIGURE 29 Case 7 B A fam 100 16 years old

patient was then given an extension brac and cycling on an ergometer bicycle and walking exercises were started After a further 4 weeks the patient was sent hom Fig 29 b

At re-examination on August 24 1964 and April 22 1965 extension had improved still more Range of motion 155 —70 He used a knee brace but could walk short distances without it

Plasma therapy Fig 31)

Before traction treatment was started the patient received 400 ml of stored plasma The haemophilia B-factor level was less than 1 % of normal before treatment From April 23 to June 30 he received all together 14 transfusions of stored plasma i e one or two transfusion a week After transfusion of 400 ml of plasma the B-factor level increased from less than 1 to 8- 10 % of normal During his stay in hospital he had no bleeding int l left knee joint or any other bleeding symptoms

Figure 30 Case 7 B A fam 100
Left knee before treatment



Figure 30 Case 7 B A fam 100
Left knee before treatment

TRACTION OF LEFT KNEE JOINT
B. A (Fam 100) 16 yrs (weight 45 kg)

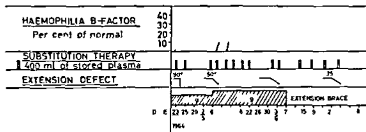


Figure 31 Case 7 B A fam 100 Treatment and course

Case 8 L B male born 1948 severe haemophilia A (family 72) Since the age of 2 years he had had recurrent bleedings in most joints For some years the mobility of the right knee the elbows and ankles was reduced He used a wheelchair because of the extension defect of the right knee for the last year In July 1964 he was referred to Malmo general hospital for treatment of the right knee

On admission extension of the right knee was found to be decreased by 50° (range of motion 130°—70°) The lower leg was rotated outwards There was an equinus position of the right foot which could not be deflected beyond 120°




FIGURE 32 Case 8 L.B fam. 72 16 years old Right knee before treatm nt

Atrophy of the thigh and calf Roentgen examination of the right knee (Fig 32) and the right ankle showed changes of the type seen in haemophilic arthropathy Extension of both elbows was slightly impaired

Treatment of the right knee joint Traction with 3 kg weight was started on July 20 1964 After a week the range of extension had improved to 10 Traction was replaced by an extension brace and active exercise (quadriceps gymnastics exercise on an ergometer cycle) was started Three weeks after the beginning of treatment the range of motion of the knee was 175°—60 Despite attempted active and passive stretching the condition of the foot remained unchanged The patient was now able to walk unaided No bleeding complications occurred during treat ment When seen again on June 28 1965 he was able to walk unaided. Range of motion of the knee was 175 —60° The ankle could be deflected to 100°

AHF dosage and plasma AHF levels (Fig 33

Before traction treatment was started the patient was given half a dose of fraction I—0 i e 100 ml Before the infusion the patient had an AHF level of 0 1 % of normal Immediately after administration of this dose the AHF level increased to 20 % After 24 hours the AHF level was 10 % and after a week 4 % In the further course he received 5 transfusions of fresh plasma (400—725 ml) at intervals of about one week. The AHF level was only determined before and after the first 2 plasma transfusions. The AHF level was 4 % and 5 % respectively before the infusions and 15 % immediately after One week after the last plasma transfusion he received half a dose of fraction I—0 The AHF level then increased from 3 % to 13 % of normal. During the traction treatment this patient received all together 2 half doses of fraction I—0 and 5 plasma transfusions

TRACTION OF RIGHT KNEE JOINT
L B (Fam 72) 16 yrs (weight 44 kg)

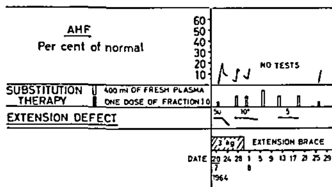


FIGURE 33 Case 8 L B f m 72 Treatment and course

Case 9 B A male born 1947 severe haemophilia B (family 183) Since the age of 5 years he had had recurrent haemorrhages into various joints mostly into the knee and elbow joints In 1961 he had been admitted to his local hospital because of heavy bleeding into the muscles of the left calf and simultaneous bleeding into the left knee joint Since then the ankle had been stiff in almost full extension and extension of the left knee was slightly defective In April 1964 he was admitted for treatment of this condition

On admission Extension of the left knee was reduced by about 20° (range of motion 160°—70°) Equinus deformity (140°) of the left foot (Fig 34 a) With the knee bent the ankle could be flexed up to an angle of 115° Severe atrophy of the thigh and calf Roentgen examination showed moderate changes of haemophilia type in the knee and ankle

Traction of the left knee joint

On April 23 1964 traction was started with a weight of 4 kg After 14 days treatment extension was only slightly impaired Range of flexion was good (175 — 70°) The equinus deformity of the foot was unchanged During the entire period of treatment the patient had received active physiotherapy (quadriceps exercise cycling) No haemorrhages occurred during treatment

Plasma therapy during treatment of knee with traction (Fig 35 a)

The haemophilia B-factor level was < 1 % of normal before treatment. During the time period April 23 and May 15 he received 6 transfusions of stored plasma On each occasion 400 ml of plasma was given After transfusion of this amount of plasma the B-factor level increased from < 1 % to about 10 % of normal

Achillotenotomy

About 8 months after the end of traction treatment the patient was admitted for treatment of the contracture of the ankle The mobility of the knee was then almost



a Left leg before treatment



b Left leg after treatment

FIGURE 34 Case 9 B A fam 183 17 years old

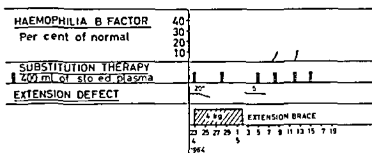
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normal (175 —30 The condition of the ankle was the same as during previous treatment On January 1? 1965 the patient was subjected to achillotenotomy and posterior capsulotomy There was no abnormal loss of blood during the operation The ankle could now be flexed to the 80? position. Pressure bandages were applied and the foot and lower leg were immobilised in plaster that was slit up in the front

Fourteen days later the sutures were removed and the plaster exchanged The wound had by then healed No haemorrhage After a further 14 days the plaster was removed and walking exercises were started (Fig 34 b)

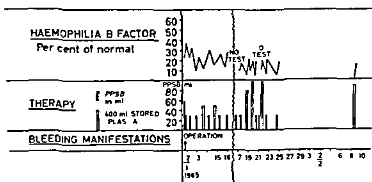
At after-examination in May 1965 the patient walked unaided The ankle could be deflected to 80

TRACTION OF LEFT KNEE JOINT
B A (Fam 183) 17 yrs (weight 46 kg)



a Traction of left knee joint

ACHILLOTENOTOMY
B A (Fam 183) 17 yrs (weight 50 kg)



b Achillotenotomy

FIGURE 35 Case 9 B A fam 183 Treatment and course

P P S B dosage and plasma haemophilia B factor levels (Fig 35 b)

The patient received 60 ml of fraction P P S B immediately before the operation 30 ml during the operation and 30 ml 5 hours after the operation The B factor level ranged between 24 and 37 % of normal No haemorrhage occurred during the operation On each of the 6 following days he received 30 ml of fraction P P S B and on the second and the third postoperative day also 500 ml of stored plasma The B-factor level varied during these days between 10 and 30 % of normal On the 7th and 8th postoperative days he received 800 and 1000 ml of stored plasma respectively The following day the patient complained of pain in the leg and as bleeding was suspected he was given 60 ml of fraction P P S B However no signs of bleeding occurred In the course of the following days he received a transfusion of 1000 ml of stored plasma on one occasion and of 30 ml of fraction P P S B

on two During this latter course the B factor level was maintained at ›—21 %
Two weeks later when the plaster was removed he received a transfusion of 900 ml of stored plasma He had no bleedings in the postoperative course

The patient received all together 420 ml of fraction P P S B and 4700 ml of stored plasma No side reactions were seen

Case 10 R. H male born 1952 severe haemophilia A (family 159) He had had recurrent bleeding into the ankle and knee joints In 1962 he had a cycle accident with heavy bleeding into the left knee joint which was also later the site of small recurrent haemorrhages During the last year he had not been able to extend the knee He used a stick when walking In October 1964 he was admitted for treatment of the extension defect

On admission Capsular swelling and slight increase in the breadth of the left knee but no exudate Slight outward rotation and valgus position Mobility 55° (145°—90) Atrophy of the thigh and almost complete inability to innervate the extensors Roentgen examination showed moderate haemophilic arthropathy

Treatment of the left knee joint On October 6 1964 traction was started with a weight of 3 kg which was increased to 4 kg after one week Traction was interrupted every day for quadriceps exercise ergometer cycling and walking exercises Owing to the difficulty in innervating the extensors treatment included faradisation After 3 weeks treatment the range of motion was 75° (165°—80°) Traction was replaced by an extension brace and physiotherapy was continued After a further 5 weeks treatment the extension defect was 10 (range of motion 170°—80°) The patient could now innervate his extensors but he could not lift the leg when extended He was also able to walk much better Owing to the valgus deformity and the poor muscle function the patient was fitted with a jointless knee brace to be used when walking outdoors Physical training was continued In July 1965 the patient could walk without a stick or knee brace Range of motion as on discharge from hospital

AHF dosage and plasma AHF levels (Fig 36)

Before traction treatment was started the patient was given half a dose of fraction I—0 i e 100 ml Before the infusion the patient had an AHF level of less than 1 % of normal Immediately after administration of this dose the AHF level increased to 14 % In the further course he received 5 transfusions of fresh plasma (400—625 ml) at intervals of about one week After injection of the plasma transfusions the AHF level increased from 1 % to values between 12 and 19 % At the end of the treatment he received half a dose of fraction I—0 because of bleeding in the left shoulder joint During the traction treatment the patient received all together 2 half doses of fraction I—0 and 5 plasma transfusions He had no bleeding into the left knee joint

Case 11 B W male born 1942 severe haemophilia A (family 62) He had had repeated bleeding of the nose kidneys and joints Severe symptoms of right leg because of varus deformity and extension defect of the knee Pain and weakness of the right knee and ankle on exertion He could only walk a few hundred metres at a time Difficulties in stepping on to bus train and the like During the last few years the symptoms had progressed Admitted for correction of the deformity

On admission in March 1965 the right knee was deformed there was an extension defect of 25 and varus of about 25 (Fig 37 a) Range of motion 65 (155 —90 Roentgen examination showed arthropathy of haemophilia type (Fig 38)

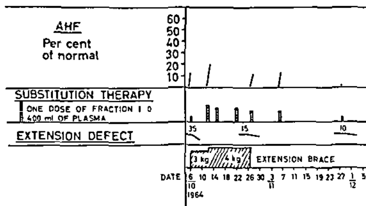


FIGURE 36 Case 10 R H fam 159 Tre tment nnd course



a Right leg before treatment



b Right leg after tre itment

FI URE 37 Case 11 B W fam 62 23 years old




FIGURE 38 Case 11 B W fam 62 Right knee before treatment

Treatment of the right knee

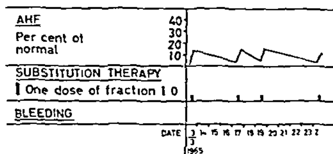
After a few weeks *physiotherapy* during which the extension defect diminshed from 25° to 10° the patient was submitted to operation with wedge *osteotomy* of the right tibia and osteotomy of the fibula on March 30 1965 Both the varus deformity and the extension defect were corrected There was no undue loss of blood during the operation The vessels were ligated with fine silk No interior fixation was used The joint was fixed in the corrected position in padded plaster which was slit up anteriorly

On the second day after the operation bleeding from the operative field was noted despite an AHF level of between 20 and 40 % Since analysis of the bone wedge removed at operation showed high fibrinolytic activity treatment with ε ACA (Epsikapron® 5 g×5 orally) was started The bleeding stopped within 24 hours On the 5th day after operation pneumonia supervened with high grade fever and prostration No explanation can be offered for this complication The patient was treated with antibiotics and breathing exercises The roentgenographic pulmonary changes disappeared rapidly When the plaster was changed 4 weeks later the wound had healed The sutures were removed

When the plaster was again changed 8 weeks after the operation a haematoma (5 by 5 cm) with a small central necrosis was seen at the site of the operation and there was still slight continuous bleeding The haematoma had caused no symptoms The patient was again treated with AHF and the bleeding stopped The haematoma was soon absorbed

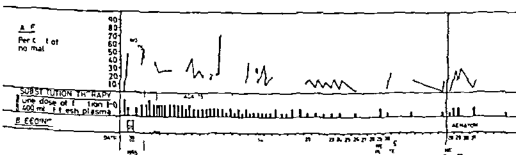
Three months after the operation the plaster was removed The osteotomy then felt consolidated and the varus deformity was corrected Walking and movement exercises were started (Fig 39)

PHYSIOTHERAPY RIGHT KNEE JO NT
B W (Fam. 62) 22 yrs (weight 50 kg)



a Physiotherapy

CSTEO OMY OF RI HT TIBIA
B W (m 62) 22 y (w ht 0 kg)



b Osteotomy

FIGURE 39 Case 11 B W fam 62 Treatment and co rse

On Sept 27 1965 five months after operation the patient could walk much longer distances than before the operation No knee pain Did not use a stick Full range of extension but flexion was still restricted (180°—135°)

AHF dosage and plasma AHF levels

Physiotherapy of right knee joint (Fig 39 a) Before physiotherapy was st rted the patient was given half a dose of fraction I—0 i e 100 ml Before the inf n the patient had an AHF level of < 1 % of normal Immediat ly after adm n of this dose the AHF level increased to 13 % After 4 days the AHF l el d and he again received half a dose of fraction I—0 In the further course he received 2 half-doses of fraction I—0 at intervals of 2 days and 5 days respectivel Th

level was 5 % and 8 % respectively before and 15 % and 12 % immediately after these infusions During the period of physiotherapy he thus received all together 4 half doses of fraction I—0 He had no bleeding into the right knee joint or other bleeding symptoms

Osteotomy of right tibia (Fig 39 b) The patient received 3 doses of fraction I—0 immediately before the operation one dose at the end of the operation and one and a half doses 6 hours after the operation These doses were sufficient to keep his AHF level above 50 % On the first postoperative day he was given one and a half doses in the morning and two doses in the evening On each of the 4 following days he received one and a half doses in the morning and one and a half doses in the evening During this period the AHF level was kept between 25 % and 45 % Between the 6th and 10th postoperative days he received one dose in the morning and one or one and a half doses in the evening which was sufficient to keep the AHF about 20 % or higher Between the 11th and 20th postoperative days he received one to one and a half doses daily and the AHF was maintained at 10—35 % During the following 3 weeks he received all together 5 and a half doses of AHF and the AHF level was kept between 4—20 %

Owing to the fresh haematoma which was discovered when the plaster was changed 8 weeks after operation the patient was given 4 doses of AHF in the course of one week

In connection with the operation the patient received 57 administrations (54 doses) of AHF

DISCUSSION

Various methods with and without cover of transfusion of blood and/or plasma have been tried in the *non surgical treatment* of contractures in haemophiliacs Thus in some cases of long standing contracture of the knee joint Skold 1944 successfully used gradual stretching with dressings in plaster under cover of blood transfusions Jordan (1958) used a fairly complicated extension brace and most of his patients were not given blood or plasma transfusions According to him the advantage of his brace is that the corrective forces are more effective than in traction and the extension occurs about a more physiological axis so that posterior subluxation of the tibia should be prevented or corrected Biggs and Macfarlane (1962) recommended gentle traction under cover of transfusion of fresh plasma but they did not give any detailed case reports

In the present material 9 patients with severe haemophilia 7 of type A and 2 of type B were treated with traction and an extension brace They had an extension defect of 20 to 90° of the knee and in all patients except one the contracture was more than half a year old The defect was corrected or reduced to 10° in 8 of the 9 patients within 4 weeks In the remaining case (case 7) the contracture which was initially 90° diminished to 35°

Immediately before orthopaedic treatment was started all patients with haemophilia A except one (case 5) were given 0.5—1 doses of AHF and afterwards 0.5—1 doses of AHF or 400—750 ml plasma about once a week throughout treatment. At the time of treatment of case 5 AHF was in short supply. AHF was therefore not given before orthopaedic treatment and only half a dose some days after treatment had been started. Haemorrhage into the treated knee occurred in this case during physical exercises 3 weeks after the infusion. The AHF in the plasma at that time was below 1 % of normal. In the remaining cases where substitution therapy was given throughout the orthopaedic treatment the AHF was as a rule above 1 %. In other words treatment had temporarily changed the haemophilia from a severe to a moderate form. In none of these cases did any haemorrhage into the knee joint occur during treatment.

The 2 patients with haemophilia B received about 400 ml of plasma a week during orthopaedic treatment. After every plasma transfusion the B-factor rose to a level of 10—15 %. In neither case was treatment complicated by haemorrhage.

Surgical treatment of contractures and deformities of bones and joints in haemophiliacs has been described in only a few cases. Pieper *et al* (1959) gave a survey of the cases of major surgery published up to 1958. Their compilation included only 2 operations on the limbs, both amputations, including one with a fatal issue. Guilleminet (1964) reported a case of femoral osteotomy performed in 1950 under cover of plasma and blood infusions. The latter course was complicated by bleeding from the operative field but the patient survived. DePalma (1956) reported 7 cases including 2 rotational osteotomies of the femur, one arthrodesis of the knee joint and one of the hip joint. None of the patients had severe haemophilia. Blood transfusions were given repeatedly in association with the operations. He stressed the risk of such operations and claimed that surgery is contraindicated in severe haemophilia. Substitution therapy with fresh blood and/or plasma — if it is to be effective in association with major operations in severe haemophilia — requires the infusion of volumes of fluid larger than what can be tolerated by the circulatory system. In such cases concentrated preparations must be used. Smaller doses of concentrated AHF in combination with large amounts of fresh blood and plasma have been used by Stefanini *et al* (1959) in the correction of a deformity of the foot in a haemophiliac with AHF 2 %. The postoperative course was complicated by repeated bleedings in the region of the operation.

Bovine AHF alone or combined with fresh blood and plasma has been

used in various quarters in association with operations on the limbs (Egeberg *et al* 1960 Biggs and Macfarlane 1962 deValderrama *et al* 1965) Egeberg s case—exarticulation of the hip joint—was complicated by copious bleeding in the region of the operation The coagulation correcting effect in the other cases was good but the antigenic properties of the animal preparations make their use unsuitable except in life threatening situations France and Wolf (1965) reported 3 operations for contractures of the lower limbs and one arthrodesis in 3 haemophiliacs at least one of whom had severe haemophilia The operations were performed under cover of plasma, bovine and human AHF The haemostatic effect was good but after 3 of the operations the patients developed symptoms of nephrosis with hyperproteinaemia and arterial hypertension owing to the infusion of such large volumes of plasma Also respiratory distress occurred in these cases

In recent years surgical operations have been carried out under cover of human preparations The fraction prepared by the method of Blomback and Blomback has been u ed since 1956 not only in the aforementioned cases but also in association with some 10 or more major operations (*e g* nephrectomy cholecystectomy) on severe haemophiliacs The course was largely uneventful in all of the cases Other authors have since used fractions prepared in accordance with similar methods Buchner and Sailer (1960) did 2 operations on knee joints one with severe and one with moderate haemophilia under cover of blood and antihaemophilic plasma In the patient with severe haemophilia the postoperative course was complicated by repeated bleeding in the region of the operation

Field *et al* (1963) described 3 haemophiliacs in whom achillotenotomy was done under cover of human fibrinogen rich in AHF In all 3 cases the patients had bleeding from the region of the operation or the nose and/or teeth Albright *et al* (1964) reported exarticulation of the hip of a haemophiliac under cover of fresh blood and plasma and human fibrinogen rich in factor VIII Postoperatively the patient had numerous episodes of major bleeding Because of the excessive volumes of fluid given he had 2 episodes of congestive heart failure both of which required treatment Lewis *et al* (1965) used plasma fraction I in association with femoral amputation in a severe haemophiliac Mild intermittent bleeding occurred from the 14th to 28th postoperative day

Concentrated preparations of B factor from human plasma have only recently become available (Soulier 1961) Biggs *et al* (1961) reported exarticulation in the elbow of a boy with severe haemophilia B under cover

of such a preparation The postoperative course was smooth Biggs (1963) recommends that attempts should be made to achieve the same plasma level of B-factor as of AHF in haemophilia A

Four patients in the present material were operated upon 3 with severe haemophilia A and 1 with severe haemophilia B

As to the operative technique used in our cases it might be mentioned that a plastic catheter for infusion was inserted percutaneously into a suitable vein before the operation This makes repeated puncture unnecessary and sparse the veins Surgical exposure of a vein should be avoided in haemophiliacs

Tourniquet was not applied to the limb bleeding being controlled as it occurred during the operation Bleeding vessels were ligated with fine silk Catgut and diathermy were not used

The 3 patients (cases 3 6 and 11) with severe haemophilia A have been subjected to 2 osteotomies and 1 arthrotomy with excision of osteophytes and partial synovectomy under cover of human fraction I—0 The AHF was maintained at a level of 20—90 % of normal during the operation and for the first postoperative week The dose of fraction I—0 was then gradually reduced On the 18th day after the operation by which time the AHF had fallen to 2 % a moderate haematoma developed in the region of the operation in case 3 The same complication occurred in case 11 eight weeks after operation when the AHF level was below 1 % The administration of fraction I—0 was increased and the further course was uncomplicated In case 6 the postoperative course was smooth In cases 3 and 11 the postoperative haemorrhages though small show the necessity of long careful observations and treatment with substitution therapy in association with bone surgery

In case 11 the operative field began to bleed on the second day after the operation in spite of the fact that the AHF level was about 25 % Since analysis of the piece of bone removed at operation showed high fibrinolytic activity as measured on fibrin plates it was thought that the bleeding might be due to local fibrinolysis Treatment with ε ACA was given The bleeding ceased within 24 hours

Astrup (1956 1958) suggested that local liberation of tissue activators may be responsible for local haemorrhage It is now known that the local fibrinolytic activity in the tissues can sustain bleeding at operations on the prostate and urinary bladder (Andersson and Nilsson 1961 Andersson 1962 McNicol *et al* 1961 Andersson 1964 Nilsson *et al* 1965) The findings of Nilsson *et al* indicate that diffuse bleeding from an operative

wound may, at least in part, be due to the effect of local fibrinolytic activators They found namely a favourable response to ε ACA in 20 cases with diffuse bleeding from the operative field in connection with various surgical procedures In these cases the fibrinolytic activity in the circulating blood was not increased In this connection it should also be pointed out that Björkman and Nilsson (1961) have shown that red bone marrow has a high content of a labile fibrinolytic activator Kwaan and Astrup (1964) have recently shown that granulation tissue is especially rich in fibrinolytic activator In view of this the high fibrinolytic activity in the bone fragment of this patient and the cessation of bleeding following treatment with ε ACA suggest that this complication may have been due to local fibrinolysis Lord *et al* (1960) have also reported fibrinolytic bleeding in association with an operation on the skeleton We therefore think that it is advisable to extend the usual substitution therapy of haemophiliacs after skeletal operations to include ε ACA

In case 9 a patient with severe haemophilia B the achilles tendon was elongated under cover of human B factor concentrate The plasma level was maintained at 24—37 % during the operation and at 10—30 % during the first week after the operation The postoperative course was smooth and no side effects of the preparation were observed

Conclusion

The few cases treated with traction and extension brace do not of course warrant any definite conclusions concerning the value of different forms of substitution therapy during non operative orthopaedic treatment They do however show that effective traction is possible without complicating haemorrhage into the joint undergoing treatment The better the coagulation defect is controlled the smaller the risk of complications It would appear that plasma transfusions are sufficient to suppress or prevent haemorrhages during traction treatment In the one case in which bleeding into the joint occurred during orthopaedic treatment the patient had not received substitution therapy the last 3 weeks before the bleeding occurred which strengthens the view that substitution therapy is desirable during this form of orthopaedic treatment The orthopaedic treatment regularly produced considerable improvement of walking ability Boys obliged to use a wheelchair or crutches could manage without them after the treatment Treatment is facilitated if it is done at an early stage before contractures and muscular atrophy have become severe (see case 7)

In those cases where the contracture or deformity cannot be satisfactorily

corrected by conservative methods surgical treatment must be considered

Previous experience has shown that substitution with blood and plasma is not sufficient for major operations on patients with severe haemophilia. The volumes of fluid necessary for haemostasis carries a great risk of complications in the form of heart failure, respiratory distress and nephrosis. Concentrated animal preparations produce good haemostasis but they have antigenic properties and should therefore be used only in life threatening situations. The only suitable substitution therapy is that using concentrated human preparations. Experience with such preparations in Sweden have shown that this preparation has good haemostatic properties and has no side effects.

The 4 operated cases in this material show that surgical correction of contractures and deformities in patients with severe haemophilia A or B *can be performed without undue risk under cover of human fraction I—0* respectively B factor preparations. The preparation must be given for a long time after the operation, probably longer after operations on the *skeleton than on soft tissue. In one of the cases minor bleeding occurred in* the region of the operation about 8 weeks after the intervention. ε ACA may also help to reduce the risk of postoperative bleeding. The operations should only be done in intimate cooperation with a coagulation laboratory where the AHF respectively B factor levels can be measured at short intervals. In view of the risk of complications such operations should only be done on strictly orthopaedic grounds. In the 4 patients operated upon the severely impaired walking ability was considerably improved after the operations.

VI Prophylaxis of Musculo-skeletal Manifestations in Haemophilia

INTRODUCTION

Joint haemorrhages and subcutaneous haemorrhages are the commonest symptoms of haemophilia (Skold 1944, Ramgren 1962 a, and others) Skold found joint haemorrhages in 90 3 % of his cases and Ramgren in 87 of 90 patients with severe haemophilia in 27 of 32 with moderate haemophilia and in 10 of 20 with mild haemophilia Haemarthroses also occur in v Willebrand s disease (Nilsson *et al* 1957 Nilsson *et al* 1959 Nilsson and Blomback 1962) in which there is AHF deficiency as in haemo philia A In 4 patients with v Willebrand s disease the author has seen changes of the same type as those seen in haemophilia On the other hand almost no joint bleedings have been reported in certain other severe coagulopathies and bleeding disorders such as factor V deficieny factor VII deficiency circulating anticoagulants afibrinogenaemia and throm basthenia (Biggs and Macfarlane 1962)

The cause of joint haemorrhages and the source of such bleedings in haemophiliacs are still obscure Astrup and Sjolin (1958) showed that tissue thromboplastin activity in synovial and fibrous capsular tissue is low in normal individuals and the local haemostasis must therefore be effected by the plasma thromboplastin activity As this activity is decreased or absent in haemophilia the local haemostasis is insufficient with the result that in the event of injury of these tissues, the lesion continues to bleed

Rodnan *et al* (1957) and others claim that subchondral and intraosseous haemorrhage accompanies haemarthrosis Such bleeding may explain the dysgenesis of the epiphyses seen in haemophilic arthropathy (Caffey and Schlesinger 1940 and others) During the period of growth the epiphyses are richly vascularised This vascularity decreases considerably after the end of this period This might help to explain the observation made by DePalma and Cotler (1956) and others in haemophiliacs namely that haemarthrosis is more common during childhood and puberty than later

Haemarthrosis often leads to permanent joint changes Attempts should be made to counteract the joint lesions by the use of a general regimen during and between bleeding episodes and by correction of the coagulation defect

The following principles in the *general prophylactic treatment* have been used in our patients

We prescribe rest for all bleeding joints until the local symptoms of bleeding i e swelling and pain have begun to subside This usually requires only a few days If the symptoms persist longer or are very severe substitution therapy is given Active exercise of the unloaded joint is then started In patients with bleeding into the knee it is important to train the quadriceps function When the muscles are strong enough weight bearing is allowed

Joint puncture is performed only if the pain is severe or if pressure necrosis is imminent Puncture is otherwise avoided because of the risk of subsequent bleeding and secondly by the fact that puncture often gives only a meagre yield because the blood in the joint has coagulated or the haemorrhage is mainly periarticular When puncture is decided upon the patient is always given substitution therapy

After the acute stage of a joint haemorrhage the patient is instructed to exercise the joint until it has if possible recovered the same degree of function as it had before the haemorrhage In some cases this exercise is performed under the supervision of a physiotherapeutist During remissions the patient should do appropriate gymnastics We recommend swimming i e all round training with only a minimum risk of traumatic haemorrhage

Prophylactic treatment with AHF In Sweden 15 patients aged 2—20 years with severe haemophilia A have been treated prophylactically with AHF (Nilsson *et al* 1962 Nilsson 1965) These patients have been treated for 1—7 years The purpose of the prophylaxis was to reduce the frequency and severity of bleeding from various organs including the joints Treatment has been given according to two principles

One series of patients consisting of 8 boys aged 3 to 20 years have been given half a dose of AHF (100 ml) every 2nd to 4th week for 1—7 years (Table 24) It is of course not possible to assess the value of prophylactic treatment of severe haemophilia A from these cases However during the prophylactic period the patients have been in a good general condition They have had bleeding episodes but these have been less severe and less frequent than formerly as shown by the annual number of days in hospital beeing lower (Nilsson *et al* 1962) After administration of half a dose of fraction I—0 the AHF rose to levels between 15 % and 40 % The AHF content then fell fairly rapidly but the last few per cent only very slowly so that during the course of the major part of the month the AHF level was 1—3 % instead of about 0 1 % i e the level before prophylactic treat

TABLE 24 Prophylactic treatment series A Treatment with 100 ml fraction I—0 every 2nd—4th week

Family	Case	Year of birth	Year when treatment started	No of adm (June 1965)
10	R A	1953	1961	59
37	C S	1951	1962	48
37	L C S	1958	1961	40
62	B W	1942	1960	74
70	S M	1950	1964	17
72	B B	1946	1960	70
72	L B	1948	1958	75
140	T B	1956	1960	83

TABLE 25 Prophylactic treatment series B Treatment with fraction I—0 on incipient symptoms of joint bleeding

Family	Case	Year of birth	Year when treatment started	No of adm (June 1965)	No of doses
4	C H N	1957	1963	18	9
32	U T	1957	1959	39	21 5
75	L T	1952	1959	36	18 5
76	L S	1942	1960	38	22
105	U B	1956	1961	57	28 5
108	P V	1945	1958	116	65 5
181	H W	1958	1961	12	6 5

ment was started According to Nilsson *et al* (1962) haemophilia appeared to change from severe to moderate form

The other series of patients consisting of 7 boys aged 2—18 years (Table 25) have not received AHF regularly but immediately on appearance of incipient symptoms of joint bleeding The purpose of this series was to find out whether such prophylaxis could prevent the development of disabling joint defects These boys who lived in the neighbourhood of Malmo and Gothenburg (1 patient) had been instructed to contact the hospital as soon as they noticed any signs of joint bleeding They usually received 0 5—1 dose of AHF on each occasion The affected joint was immobilised immediately but 2 or 3 days later physiotherapy was started The patients have so far received from 12 to 116 administrations of AHF in the course

of 2 to 6 years Three of these boys (L T U B H W) have not devel oped disabling joint deformities Four of the remaining boys had joint changes already before treatment but no further defects have appeared The number of cases and the duration of treatment are however not sufficient to expect any demonstrable difference between treated and un treated age matched patients

PRESENT STUDY

On the basis of the data presented in Chapters III and IV principles of *prophylactic treatment with AHF were devised*

Dosage

It has been shown (Fig 17) that the joint score rapidly decreases with rising plasma levels of AHF or B factor At plasma levels above 3 % chronic arthropathy is rare and even when it does occur it is only mild This also holds for the degree of disability (p 44) These findings suggest that chronic arthropathy could be prevented if the plasma concentration of pertinent coagulation factors could be kept above a critical level From a practical point of view it seems that a level of about 3 % of normal would be enough in most cases

Two boys with severe haemophilia A received half a dose (100 ml) AHF at about 2 weeks interval The AHF level in the plasma which was checked before each infusion varied between 0 5 and 4 % (Figs 40 and 41) Maintenance of the value above the desirable 3 % level thus seems to require infusions at shorter intervals or a larger dose But even with the dose given the AHF level was above 3 % during a major part of the time between consecutive infusions

Age range for Prophylaxis

Chronic joint changes were not common in the 0—9 year age class (p 22) In 6 patients with severe haemophilia and below 5 years of age only one patient showed joint changes (L C S fam 37) After this age the fre quency and degree of joint lesions increased successively with age In severe haemophilia joints were rarely involved for the first time after the age of 20 (Fig 19 a) This may be due to the fact that the usually engaged joints (knee ankle elbow) then were affected Another reason may be that joint bleedings are less common in adult patients than in young children and

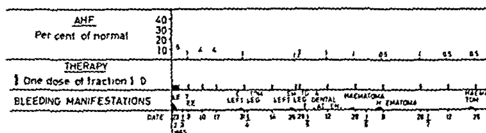


Figure 40 Prophylactic AHF treatment H W fam 181

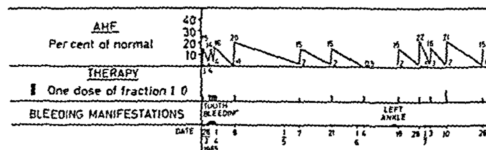


Figure 41 Prophylactic AHF treatment L T fam 75

adolescents (DePalma 1956 Eyring et al 1965) *Lesions in already affected* joints tended to progress This may be due to progressive arthrosis deformans on the basis of joint lesions that occurred already before this age and that were largely due to dysgenesis of the epiphyses *In severe* haemophilia the degree of disability did not increase with certainty after the age of 15—20 years in this material (Fig 23) It would therefore appear sufficient to begin prophylaxis with AHF at the age of about 5 and to continue it until the end of the period of growth *i e* 15—20 years

Practicability of Prophylaxis with AHF and B factor

In Sweden there are at present about 50 persons aged 5—20 years with severe haemophilia A Prophylaxis according to the principles set forth above would require about 1000 doses of AHF a year Such treatment would presumably reduce the number of doses otherwise necessary in the treatment of bleeding episodes and the correction and surgical treatment of joint deformities as well as the need for hospital care It would therefore appear warranted to give such prophylaxis as far as circumstances allow

The same principles hold also for haemophilia B It may be possible to use a *smaller dose because the half time of B factor is longer than that of* AHF According to Biggs (1963) the half time of AHF is 14 hours that of B factor 16—30 hours

VII Summary

MATERIAL AND METHODS

The clinical material consisted of 242 of the 308 known haemophiliacs (A and B) in Sweden The investigation included *clinical examination* of all major joints in 95 of 116 patients with severe haemophilia in 38 of 65 patients with moderate haemophilia, and in 24 of 127 patients with mild haemophilia and roentgen examination of practically all joints found to be abnormal at the clinical examination In addition information about 7 patients with severe haemophilia 21 with moderate haemophilia and 57 with mild haemophilia was obtained by *questionnaire* only

The degree of arthropathy (Grades 2 3 and 4) was classified largely according to DePalma and Cotler (1956) Evaluation of general disability was made with regard to ability to manage (walk dress, eat, toilet) without help This latter evaluation comprised also extra articular manifestations of haemophilia

INCIDENCE OF MUSCULO SKELETAL MANIFESTATIONS IN HAEMOPHILIA

No difference was found between haemophilia A and haemophilia B regarding incidence, type and degree of associated arthropathy The incidence and degree of arthropathy increased with the severity of haemophilia In patients with a plasma concentration of AHF or B factor above 3 % of normal arthropathy was rare Arthropathy involving the knee elbow and ankle joints was common the hips shoulders, and wrists were less often affected and the hands and feet were rarely involved Knee joint affection occurred in 4 out of every 5 patients with severe haemophilia in every other one with moderate haemophilia and only occasionally in patients with mild haemophilia Both in moderate and severe haemophilia knee affection when present was often of Grade 3 or 4 and it was bilateral in two thirds of those with severe and one third of those with moderate haemophilia Six joints were found to have bony ankylosis Joint changes

were rare in patients below 5 years Above this age they became increasingly common and then quicker in severe than in moderate haemophilia

Extra articular involvement of the musculo skeletal system was less common than arthropathy Four neurogenic and 8 myogenic lesions were found to cause deformity and 6 cases of haemophilic pseudo-tumour were demonstrated

DISABILITY DUE TO MUSCULO SKELETAL MANIFESTATIONS IN *HAEMOPHILIA*

Disability due to musculo-skeletal deformities was common in severe haemophilia and sometimes occurred in moderate haemophilia Half of the patients with severe haemophilia and one fourth of those with moderate haemophilia had difficulties in walking but only 1 individual in the entire material was permanently confined to bed The degree of disability increased markedly with age up to 20 years

CORRECTION OF MUSCULO SKELETAL DEFORMITIES IN *HAEMOPHILIA*

In 9 patients with severe haemophilia A or B knee joint flexion deformity was corrected under cover of AHF (human fraction I—0) or plasma The methods employed were continuous traction for 2—3 weeks extension braces and intense physiotherapy The importance of adequate correction of the coagulation defect during treatment was discussed *An improvement* of walking capacity was noted in all of the cases Six patients who had formerly used crutches or a wheel chair no longer required such aids After the end of treatment several of the boys could cycle or go skiing

In 3 cases of severe haemophilia A and 1 case of severe haemophilia B *were orthopaedic operations done under cover of human fraction I—0 or* human B factor concentrate one supracondylar wedge osteotomy to correct valgus deformity of the knee one tibia osteotomy to correct varus deformity one arthrotomy of the knee with removal of osteophytes and partial synovectomy and one correction of equinus deformity of the foot with lengthening of the Achilles tendon and posterior capsulotomy The post operative course was favourable in all The operations have considerably improved walking in all of the patients The necessity of keeping the AHF or B factor plasma levels sufficiently high during the postoperative period was stressed

PROPHYLAXIS OF MUSCULO SKELETAL MANIFESTATIONS IN HAEMOPHILIA

Chronic arthropathy hardly ever occurred at plasma levels of AHF or B factor higher than 3 % of normal Experience with AHF indicates that administration once every other week in severe haemophilia will maintain plasma levels at about 3 % of normal during most of the period It would thus seem possible largely to prevent the occurrence of disability in haemophilia Prophylactic treatment should be started when the child is about 5 years old and should be continued throughout adolescence

VIII Acknowledgements

Financial support was obtained from research grants awarded to Professor Goran C H Bauer from the U S Public Health Service (NIDR Grant No DE 1452 and General Support Branch Grant No 1 S01 FR 05495) to Dr Inga Marie Nilsson from the Swedish Medical Research Council and from the National Institutes of Health Public Health Service (Grant No H 07066) and to the author from Kvallspostens Fond Till Forman for Handikappade Barn Fonden for Blodsjukdomarnas Bekampande and the Faculty of Medicine The University of Lund

IX Coded Data

SYMBOLS

Se =severe
Mo=moderate
Mi =mild

Arthropathy

0=No arthropathy clinically and roentgenologically examined
2=Grade 2
3= 3
4= 4

0=No arthropathy clinically examined
2=Grade 2
3= 3
4= 4

Extra articular lesions

a=neurogenic lesions
b=myogenic
c=pseudotumor

Degree of disability

0=none
1=mild
2=marked
3=severe

Treatment

a=nonsurgical correction
b=surgical
c=prophylaxis

Fam No	Case	Year of birth	Type of haemoph	AHF or B factor % of normal	Hip R	Hip L	Knee R	Knee L	Ankle R	Ankle L	Foot R	Foot L	Shoulder R	Shoulder L	Elbow R	Elbow L	Wrist R	Wrist L	Hand R	Hand L	Extra-art lesions	Degree of disability	Treatment
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
4	C H N	1957	A Se	< 1	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0		1	c
4	H N	1962	A Se																				
5	R I	1903	A Mi	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
6	H A	1899	A Mi	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
8	K I C	1909	B Se	< 1	3	0	4	4	3	3	0	0	0	3	3	4	0		0		a	3	
9	F F	1911	A Mo		0	0	4	4	0	3	0	0	0	0	3	3	0	0	0	0		2	
9	S M	1913	A Mo	1—2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0		1	
10	Y A	1935	A Se	< 1	0	0	4	4	4	4	0	0	3	3	3	3	2	2	0	0		2	
10	R A	1953	A Se	< 1	0	0	0	3	3	0	0	0	0	0	2	3	0	0	0	0		2	c
11	B I	1937	A Se	< 1	0	0	4	4	2	0	0	0	0	0	0	0	0	0	0	0		2	
11	K L	1944	A Se	< 1	0	0	2	3	4	2	0	0	0	0	3	0	0	0	0	0		3	
12	T B	1934	A Se	0	0	0	3	3	2	2	0	0	0	0	3	3	0	0	0	0		3	
13	L E H	1919	A Mi																				
13	N O H	1924	A Mi	8																			
13	T L	1910	A Mi																			0	
13	K F T	1923	A Mi	7																		0	
13	C J	1931	A Mi	10																			
13	B F	1944	A Mi																				
14	B C	1922	B Mo	1 8	0	0	4	4	3	2	0	0	0	0	4	4	0	0	0	0	b c	3	
14	S C	1928	B Mo	2	0	0	3	3	0	0	0	0	0	0	3	3	0	0	0	0	c	2	
14	K D	1962	B Mo	3																			
18	C B	1912	A Se	< 1																			
18	N C W	1930	A Se	< 1	4	0	4	4	4	2	0	0	3	3	3	4	0	0	0	0		3	
22	B F	1918	A Se		0	0	3	4	0	0	0	0	0	0	3	0	0	0	0	0		3	
22	R K	1940	A Se	0 5	0	0	3	2	[illegible]	2	0	0	0	0	2	4	0	0	0	0		2	
22	F K	1951	A Se	0 5	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0		1	
27	A P	1907	A Mo	2	0	0	2	2	3	3	0	0	0	0	0	3	0	3	0	0		1	
27	M H	1921	A Mo	2	0	0	3	3	2	2	0	0	0	0	3	2	0	0	0	0		2	

7	G H	1923	A M	1	0 0	3 3	3 2	0 0	0 0	3 3	0 0	0 0			
27	G A	1919	A Mo	1	0 0	4 4	3 3	0 0	4 4	4 4	2 3	0 0		3	
27	O P	1911	A Mo	1 8	0 0	3 2	0 3	0 0	0 0	2 0	4 0	0 0		1	
27	A A	1941	A Mo	1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
27	I J	1916	A Mo	1	0 0	2 0	0 0	0 0	0 0	0 2	0 0	0 0		0	
27	B J	1947	A Mo	1	0 0	0 0	0 0	0 0	0 0	0 3	0 0	0 0		1	
27	B K	1952	A Mo	1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
28	C S	1920	A Se												
28	S W	1936	A Se	<1	0 0	3 3	2 3	0 0	2 0	3 2	0 0	0 0		2	b
31	K O K	1913	B Se	0 9	0 0	4 4	3 3	0 0	0 0	3 3	0 0	0 0		2	
31	K P	1932	B Se	0 3	3 0	4 0	0 3	0 0	0 0	4 4	0 0	0 0		2	
31	L G P	1954	B Se	<1	0 0	0 3	0 0	0 0	0 0	0 0	0 0	0 0		3	
31	N S N	1961	B Se	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
32	U T	1957	A Se	0 1	0 0	0 0	2 0	0 0	0 0	0 0	0 0	0 0		0	c
32	T S	1953	A Se	0 1	0 0	0 3	0 0	0 0	0 0	2 0	0 0	0 0		1	
34	O L	1938	A Se	<1	0 0	4 2	4 0	0 0	0 0	2 4	0 0	0 0	b c	2	
35	R L	1917	A Se	<0 5	0 0	3 3	0 0	0 0	3 0	4 4	0 0	0 0		2	
35	H L	1926	A Se	<0 5	0 0	2 3	0 2	0 0	4 0	3 3	0 0	0 0		1	
36	I L	1929	A Se	<0 1	0 0	4 4	3 3	0 0	3 0	3 3	3 3	0 0		2	
37	C S	1951	A Se	0 5	0 0	3 2	0 0	0 0	0 0	0 0	0 0	0 0		2	c
37	L C S	1958	A Se	<1	0 0	3 0	2 0	0 0	0 0	0 0	0 0	0 0		1	c
40	S H	1952	A Se	0 6	0 0	0 2	0 0	0 0	0 0	2 0	0 0	0 0		0	
41	K R O	1904	B Mi	6											
41	K C O	1916	B Mi	10											
41	K I	1925	B Mi												
42	B R	1924	A Se	0 1	3 0	3 3	4 3	0 0	0 0	3 4	0 3	0 0	b	2	
43	S P	1901	A Mo	3 3										0	
43	B P	1904	A Mo	6										0	
43	O P	1906	A Mo	2 6										0	
44	J Ö	1955	B Se	0 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
45	G S	1898	A Mo												
46	B S	1921	A Se	0 1	0 0	4 2	4 3	3 4	0 2	3 3	3 2	0 0	b	2	
48	L W	1926	A Se	0	0 0	3 3	2 2	0 0	4 4	4 4	0 3	0 0		2	
49	S Ö	1921	B Mo	1—2	0 0	0 0	3 0	0 0	0 0	2 3	0 0	0 0		0	
54	T K	1919	A Mi	9											

1	2	3	4	5	6 7	8 9	10 11	12 13	14 15	16 17	18 19	20 21	22	23	24
51	R N	1913	A Mi											0	
51	K I K	1937	A Mi	5											
51	I C N	1919	A Mi	9											
56	A J	1923	B Se	< 1	0 3	4 3	3 3	0 0	0 3	3 3	0 0	0 0		2	
5	C J	1931	B Se	< 1	0 0	3 3	2 3	0 0	0 0	3 3	0 0	0 0		1	
57	J S	1906	A Se	< 1	0 0	4 4	3 3	0 0	3 3	3 3	0 0	0 0		2	
5	H H	1947	A Se											0	
53	U H	1937	A Mo	4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
59	R B	1951	B Se	< 1	0 0	3 0	0 2	0 0	3 0	0 0	0 0	0 0		2	
60	I R	1893	B Se	< 1	0 0	4 4	4 4	0 0	1 3	4 4	3 3	3 3		2	
61	L O C	1911	B Se	< 0 5	0 0	3 2	2 3	0 0	0 0	3 3	0 0	0 0		1	
61	S I	1910	B Se	< 0 5	0 0	3 0	3 3	0 0	0 1	3 3	0 0	0 0		3	
61	C I	1914	B Se	< 0 5	0 0	3 3	0 0	0 0	0 0	3 3	0 4	0 0	b	2	
63	B W	1912	A Se	0 3	0 0	3 2	2 2	0 0	0 0	3 3	0 0	0 2		2	b c
64	J H I	1951	B Mi	8	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
64	I I	1953	B Mi	11	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
64	N I	1953	B Mi	8	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
65	B J	1918	A Mi	9 –14										0	
67	J A J	1947	A Se	< 1										2	
68	C F	1930	A Se	< 1	0 0	4 3	0	0 0	0 0	4 3	0 0	0 0	a	2	
68	O F	1936	A Se	< 1	2 0	3 3	0 0	0 0	0 0	4 4	0 0	0 0		2	
69	F G	1910	B Mi	8										0	
70	S M	1950	A Se	< 1	0 0	3 3	0 0	0 0	0 0	0 0	0 0	0 0		2	c
71	J A	1884	B Mi	8—10										0	
71	B A	1941	B Mi	9										0	
72	B B	1916	A Se	0 1	0 0	4 4	4 4	0 0	0 0	3 2	0 0	0 0		3	c
72	I B	1918	A Se	0 1	0 0	3 0	3 3	0 0	0 0	3 3	0 0	0 0	b	3	a c
73	A J	1915	A Se	< 1	0 4	0 0	0 0	0 0	0 0	2 3	0 0	0 0		1	
74	I R C	1951	A Se	< 1	0 0	2 3	0 0	0 0	0 0	0 0	0 0	0 0		3	a
75	I T	1952	A Se	< 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	c
76	I S	1919	A Se	< 1	0 0	3 3	0 0	0 0	0 0	3 3	0 0	0 0		1	c
77	I S	1919	A Se	< 1	0 0	3 2	0 0	0 0	0 0	4 0	0 0	0 0		2	

77	S S	1955	A Se	<1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
78	B E	1955	A Se	<1										3	
79	A M	1922	A Mi												
79	S J	1933	A Mi												
79	B J	1938	A Mi												
80	L N	1936	A Se	<1	0 0	3 3	0 0	0 0	0 0	2 0	0 0	0 0		1	
80	R P	1958	A Se	<1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
81	U J	1951	A Mo	2	0 4	0 0	0 0	0 0	0 0	0 0	0 0	0 0		1	
82	E W	1933	A Se	<1										1	
82	R H	1950	A Se	<1										2	
83	P O	1946	A Se	<1	0 0	4 4	3 2	0 0	2 0	3 3	0 0	0 0	c	2	
84	R H	1938	A Se	<1	0 0	3 3	3 3	0 0	2 0	3 3	0 0	0 0		2	
85	B C	948	A Se	<1	0 0	3 2	0 0	0 0	0 0	2 3	0 0	0 3		2	
86	G S	1945	A Se	<1	0 0	3 2	0 0	0 0	0 0	2 0	0 0	0 0		1	
87	R F	1949	A Mo	11	0 0	2 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
89	K A	1943	A Se	0	0 0	0 3	0 0	0 0	0 0	2 2	0 0	0 0		1	
90	P B	1956	A Se	<1	0 0	0 2	0 2	0 0	0 0	0 3	0 0	0 0		1	
91	M G	1960	A Se												
92	B F	1942	A Se												
93	G R	1938	A Mi	11										0	
93	I G	1935	A Mi	8										0	
94	A K	1895	A Mi	12										0	
94	K K	1904	A Mi	10										0	
95	B M	1946	A Se	<1	0 0	4 2	0 0	0 0	0 0	3 3	0 0	0 0		3	a b
95	I M	1954	A Se	<1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
96	R A	1943	A Mi	15	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
97	R F	1926	A Mo	2	0 0	3 3	0 0	0 0	0 0	3 0	0 0	0 0		1	
99	G G	1947	B Se	01	0 0	3 2	3 3	0 0	0 0	3 3	0 0	0 0		1	
100	B W	1914	B Se	<1	0 0	3 4	3 3	0 0	0 4	4 4	0 0	0 0		2	
100	B A	1948	B Se	<1	0 0	2 4	0 0	0 0	0 0	2 0	0 0	0 0		3	t
101	K G J	1944	B Mo	2										0	
102	H I H	1946	A Mi	7—8										0	
103	L G J	1947	A Se	<1	0 4	4 4	2 2	0 0	0 0	4 4	0 0	0 0		3	
104	N V	1926	A Mi	16	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
104	J V	1937	A Mi	5										0	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
105	L B	1956	A Se	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	c
106	S O J	1955	A Se	<1	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0		1	a
107	S O	1925	A Mi	11																		0	
108	I A	1945	A Se	0 1	0	0	2	2	0	0	0	0	0	0	3	3	0	0	0	0		1	c
109	U P	1913	B Mo																				
109	G A	1943	B Mo	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
110	J H	1912	B Se	0	0	0	4	2	3	2	0	0	0	0	2	2	0	0	0	0		2	
111	E N	1929	A Mo	2—3																		1	
11	S J	1943	B Se	0	0	0	0	2	0	0	0	0	0	0	3	0	0	0	0	0	a	2	
113	R A	1939	A Mo	2																		0	
114	T J	1937	A Se																				
114	B J	1957	A Se	0 7																			
115	B I	1904	A Mi		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
115	A P	1922	A Mi	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
116	U O	1956	B Se	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
118	C I	1955	B Se	0 9	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0		1	
119	J M	1956	A Se	0 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
120	L F A	1957	A Se	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
121	I H	1935	A Se	<1	0	0	2	3	0	0	0	0	0	0	4	2	0	0	0	0		2	
122	R B	1915	A Mi	16																		0	
122	K B	1918	A Mi																			0	
122	I B	1920	A Mi	5—7																		0	
123	P A	1883	A Mi																				
123	K A	1949	A Mi	5—6	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	b	1	
124	F H	1930	B Mo	1 4	0	0	3	3	0	0	0	0	0	0	3	0	0	0	0	0		1	
125	S A I	1939	B Mi																			0	
126	I J	1957	A Mi	5—6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
127	A P	1888	A Mi	4																		0	
127	C F	1915	A Mi	10																			
129	R J	1919	A Se		0	0	2	0	0	2	0	0	0	0	2	0	0	0	0	0		0	
131	H S	1955	A Mo																			0	
132	A M	1915	A Mo	3	0	0	0	0	2	2	0	0	0	0	3	4	0	0	0	0		1	

133	S B	1915	A M	4—5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
133	S C K	1928	A Mo	5—3 9									0
133	A K	1934	A Mo	3 3									0
134	S N	1919	B Mo	2 6									
135	L T	1937	A Mi	7	0 0	0 0	3 0	0 0	0 0	0 0	0 0	0 0	1
136	G P	1908	A Mo		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
137	A F	1935	A Mi	5									0
138	T H	1942	A Mo	1 5									2
139	T E	1947	B Mi	8									0
140	T B	1956	A Se	0 4	0 0	3 0	0 0	0 0	0 0	0 0	0 0	0 0	1
141	O F	1918	A Mi	24									0
141	I F	1926	A Mi	20									0
142	H E K	1946	A Se	< 1	2 3	3 3	3 3	0 0	0 0	3 3	0 0	0 0	2
143	K J	1923	A Se	< 1	0 0	1 4	3 0	0 0	0 0	4 4	0 0	0 0	2
144	J F K	1941	A Mo	1 7									2
144	B N	1939	A Mo	1 3	0 0	0 3	0 0	0 0	0 0	0 2	0 0	0 0	2
144	O L	1916	A Mo										1
145	A H	1927	A Mi	21	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
145	H H	1942	A Mi	23	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
145	K H	1953	A Mi	21	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
145	R H	1956	A Mi	20	0 0	2 2	0 0	0 0	0 0	0 0	0 0	0 0	0
146	S P	1928	A Mi	21									0
148	P W	1956	A Mo	1 5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
149	A S	1930	A Mi	5									
150	K R C	1907	B Mo	4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
150	R F	1955	B Mo	4	0 0	2 2	0 0	0 0	0 0	0 0	0 0	0 0	1
151	T K	1959	B Se	0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
152	S B	1918	A Mo	4									0
153	B L	1915	B Mo	1	0 0	2 0	0 0	0 0	0 0	3 0	0 0	0 0	1
154	B E	1947	A Mi	8	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
154	R E	1950	A Mi	5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
155	A F	1904	A Mo	3									3
156	K F	1953	A Mi										0
157	O B	1899	A Mi										
157	F J	1909	A Mi										

1		3	4	5	6 7	8 9	10 11	12 13	14 15	16 17	18 19	20 21	22	23	24
157	I I	1919	A Mi											0	
157	S E A	1913	A Mi											0	
15	K R	1918	A Mi											0	
157	J E R	1937	A Mi											0	
158	S K	1939	A Se	0 1										1	
159	R H	1937	A Se	< 1	0 0	0 3	0 0	0 0	0 0	0 0	0 0	0 0		3	a
160	S I	1927	A Mo		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
160	I I	1931	A Mo	2 5										0	
160	I I	1935	A Mo	2 7										0	
161	B M	1938	A Mo	2	0 0	3 3	3 3	0 0	0 0	2 3	2 0	0 0	b	1	
162	K A	1918	A Se	0 1	0 0	3 3	0 0	0 0	0 0	2 2	0 0	0 0		1	
163	O O	1895	B Mi		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
163	H H	1938	B Mi		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
163	B O	1913	B Mi	20											
163	I O	1917	B Mi	18											
164	B I O	1943	A Se	< 1	0 0	3 3	2 2	0 0	3 0	0 3	0 0	0 0		0	
165	I O	1917	A Mo											1	
166	I R O	1892	A Mo	3										0	
167	O O	1903	B Mi	9										1	
167	H K	1956	B Mi	10											
168	I S	1927	A Se	< 1	0 0	4 4	0 0	0 0	0 0	3 2	0 0	0 0		0	
169	B S	1909	A Mo	12	0 0	4 4	3 2	0 0	3 3	3 2	3 3	0 0		2	
170	I W	1913	A Mo	1									c	3	
171	I A	1911	B Mo	3	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
172	J B	1908	A Se	0 1										0	
173	I B	1954	B Mo	3	0 0	0 2	0 0	0 0	0 0	0 0	0 0	0 0		2	
174	B S	1928	A Mi	9 5										0	
174	D S	1935	A Mi	12										0	
175	I W	1956	A Se	< 1	0 0	3 0	0 0	0 0	0 0	0 0	0 2	0 0			
176	I C I	1959	B Se	< 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		3	a
177	B H	1930	B Mi	10										0	
177	S H	1938	B Mi	12										0	
														0	

177	TRS	1951	B M	9	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
178	ML	1938	A Mo	2										0	
179	GL	1945	A Se	<1	0 0	0 0	? 0	0 0	0 0	0 0	0 0	0 0		0	
180	IOK	1939	B Se	1 4	0 0	3 3	2 2	0 0	0 0	3 3	0 0	0 0		1	
180	GK	1943	B Se	1 4	0 0	3 2	0 2	0 0	0 0	4 3	0 0	0 0		1	
181	HW	1958	A Se	0 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
182	IE	1938	A Se	<1	0 0	3 3	2 2	0 0	0 0	4 4	2 2	0 0		2	c
183	BA	1947	B Se	<1	0 0	2 3	0 2	0 0	0 0	3 2	0 0	0 0	b	2	a b
184	PB	1955	A Mo	2 6	0 0	0 2	0 2	0 0	0 0	2 0	0 0	0 0		1	
184	TB	1958	A Mo	3—4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	a	2	
185	AE	1954	B Mi												
186	AM	1960	A Se	0 4											
187	JL	1890	A Mi	16											
188	LP	1949	A Mi	8	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		0	
189	IO	1958	A Se	0 7											
189	SO	1960	A Se												
190	ME	1926	A Se	<1	3 0	4 4	2 2	0 0	2 0	3 0	0 0	0 0	c	2	
191	JEC	1953	A Mi	6										0	
192	ML	1918	A Mo	2	0 0	2 0	2 0	0 0	0 0	0 0	0 0	0 0		0	
193	PG	1943	A Mi	22										0	
193	ST	1936	A Mi	24											
194	AA	1922	A Mi	25										0	
195	RB	1940	A Mi	23										0	
195	RB	1946	A Mi	25										0	
195	KP	1945	A Mi	30										0	
196	KA	1961	A Se	0 2											
197	EM	1891	A Mi	13										0	
197	OM	1896	A Mi												
198	KW	1943	A Mi	11											
199	DS	1912	A Mo	4										0	
200	BJ	1959	A Mo	2											
201	BJ	1933	A Mo	1 1	0 0	0 ?	0 0	0 0	0 0	0 0	0 0	0 0		0	
201	SS	1935	A Mo												
202	ES	1919	B Mi	15										0	
203	KS	1919	A Mi	6										2	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
01	R D	1979	A Mi																			0	
01	I C	1918	A Mi	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
01	H C B	1938	A Mi																			0	
201	A G	1925	A Mi	11																		0	
205	A G S	1925	A Mi	21																			
206	I F	1938	A Mi	20																			
206	K I	1914	A Mi	20																			
207	I G K	1959	A Se	0 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
208	I S	1960	A Mo	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
209	B A A	1961	A Se	0 8																			
210	I C I	1936	A Se	< 1	3	0	3	3	3	0	0	0	0	0	4	3	0	0	0	0		2	
212	B I	1910	A Mi	8																			
212	L I	1901	A Mi	8																		0	
212	B A I	1910	A Mi	9																		0	
212	E I	1920	A Mi	6																			
213	I E H	1953	A Se	0 5	0	0	2	4	0	0	0	0	0	0	0	3	0	0	0	0		2	a
214	J J	1942	B Mi	5																		0	
215	S P	1957	B Se	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0		0	
216	I F	1953	A Mi	13																			
216	C M	1955	A Mi	8																			
217	E K	1911	A Mi	23																			
217	S K	1926	A Mi	32																			
217	I C	1950	A Mi	35																		0	
218	K R	1917	A Mi	21																		0	
218	R R	1919	A Mi																				
219	F P	1933	A Mi	36																			
220	S A A	1937	A Mi	11																		0	
220	A H	1928	A Mi	11																		0	
221	T H	1957	B Mi	14																			
222	A A	1931	A Mi	6																			
222	M N	1930	A Mi	5																			
223	H N	1933	A Mi	12																		0	

? 3	G N	1?35	A M	9									
23	R N	1?37	A M	10									
?23	C N	1946	A Mi	14									0
224	T O	1959	A Mi	14									0
2?4	L T	1960	A Mi	5									
225	J O L	1952	A Mi	18									0
?26	K S	1949	A Mi	25									
226	R W	1950	A Mi	23									
227	M L	1961	A Se	0 5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
228	J K	1938	B Mi	21									
2?9	J H	1934	B Mi	16									
230	V N	1913	A Mi	10									

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From the Coagulation Laboratory University of Lund Malmö General Hospital Malmö and the City of Stockholm Blood Transfusion Centre and the Coagulation Research Laboratory Karolinska Institutet Stockholm Sweden

Addendum

TO THE REVIEW OF HAEMOPHILIA IN SWEDEN IN 1962

By

INGA MARIE NILSSON OLOF RAMGREN
MARGARETA BLOMBÄCK and ÅKE AHLBERG

A review of haemophilia in Sweden was published by Sköld in 1944 He investigated 60 families with 101 living haemophiliacs Sköld studied the hereditary pattern in the Swedish families the symptomatology of the haemophiliacs the coagulation time of whole blood in the haemophiliacs and the carriers and evaluated the effect of blood transfusion therapy in haemophilia In 1955 Nilsson Blombäck and Ramgren started a follow up study of Sköld s investigation and in 1961 and 1962 they published a new review of haemophilia in Sweden All together 179 haemophilic families in Sweden with 253 living haemophiliacs were investigated This review included the coagulation status of the haemophiliacs (Nilsson *et al* 1961) and the carriers (Nilsson *et al* 1962) the symptomatology of haemophilia A and B (Ramgren 1962 a) hereditary investigation (Ramgren *et al* 1962) medico-social aspects (Ramgren 1962 b) and the treatment of haemophilia A with human AHF preparations (Nilsson *et al* 1962) A short case history was compiled for each haemophiliac as well as a pedigree of the family

Since 1961 a further 50 families with haemophilia have been discovered in Sweden In addition 4 affected members have been born in the 180 *previously known families Coagulation studies have been carried out on* 42 haemophiliacs belonging to families 1—180 and not tested in the previous investigation In addition 18 patients have been re examined either because check analysis had shown that the previous tests had been incomplete or that the results of the tests deviated from those obtained in

Aided by grants from the Swedish Medical Research Council (Project No 19X-87-01 and Project No 19X-613-01) and the National Institutes of Public Health (Grant No H-07066)

— Ahlb

the remaining affected family members or appeared incompatible with the clinical course

The information obtained on the hereditary pattern symptomatology and coagulation status in these cases is given in this addendum All together 230 haemophilic families were known in Sweden in January 1964

The methods used for collection and preparation of the blood samples and for determination of the various coagulation factors have been described elsewhere (Nilsson *et al* 1961)

Histories of additional cases in fam 1—180

THE SYMBOLS USED IN THE PEDIGREES

- NORMAL WOMAN
- NORMAL WOMAN CHILDLESS
- FEMALE GENETIC CARRIER
- FEMALE GENETIC CARRIER EXAMINED BY COAGULATION TESTS
- FEMALE CARRIER ACCORDING TO COAGULATION TESTS
- FEMALE HAEMOPHILIAC
- NORMAL MAN
- HAEMOPHILIAC
- HAEMOPHILIAC EXAMINED BY COAGULATION TESTS
- PROBABLE HAEMOPHILIAC
- DESCENDANTS NUMBER AND SEX UNKNOWN OR OF NO INTEREST

V 9 GENERATION V MEMBER NO 9 AS COUNTED FROM THE LEFT
DESCENDANTS DESIGNED AS ◇ ARE NOT COUNTED

Family 4 Haemophilia A severe form

VI 4 (H V) Born 1962 First symptom of haemophilia at 1 year Has had haemarthrosis *in ankle joints which have not impaired the* joint function

Family 14 Haemophilia B moderate form

Son of IV 6 (K D) Born 1962 First symptom of haemophilia at 1 year (large haematoma in the forehead) He has had several large sub cutaneous and intramuscular haematoma No haemarthroses

Family 31 Haemophilia B severe form

VI 4 (S N) Born 1961 First symptoms of haemophilia at *1 year (subcutaneous bleedings)* He has had several large subcutaneous bleed ings Recurrent haemarthroses in knee ankle and elbow joints Hospitalized on several occa sions Has received blood and plasma trans fusions

VI 5 (H N) Born 1962 First symptom of haemophilia at *3—4 months (subcutaneous* bleedings) He has always been covered with haematomas At 2 years he bit his tongue and bled heavily Then given one blood transfusion and 2 plasma transfusions Haemarthroses in knee and elbow joints Often hospitalized and blood transfusions on several occasions

Family 105 Haemophilia A severe form

III 5 (A N) Born 1934 This patient was in cluded as a haemophiliac in the foregoing re view Recent clinical examination and coagula tion studies revealed no symptoms of haemo philia and a normal AHF content

Family 130 Haemophilia A mild form

(K E P) *Born 1936 In the preceding paper* (Ramgren 1962) this patient was described as having mild haemophilia A Repeated recent examinations however showed a normal AHF and B-factor content which thus excludes haemophilia

Family 134 Haemophila B moderate form

II 3 (S N) *Born 1919 This patient is the* same as case III 5 (S P) in family 109 The family has been registered twice because on two occasions the patient had used different sur *names*

Family 177 Haemophilia B mild form

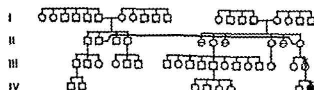
V 3 (T R S) Born 1951 First symptom of haemophilia at 4 years (profuse wound bleeding) He has had several large intramuscular and subcutaneous haematomas No haemarthrosis No operations have been performed No transfusions He attends school

Histories of cases in fam 181—230

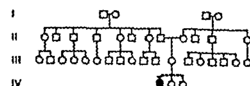
Family 181 Haemophilia A severe form

IV 8 (H W) Born 1958 First symptom of haemophilia at 6 weeks (subcutaneous haemorrhage) Repeated hospitalization for haemarthroses and intramuscular bleedings No disabling joint changes He has received fraction I—O on about 40 occasions Since March 1965 he has been receiving half a dose every other week prophylactically

FAMILY 181



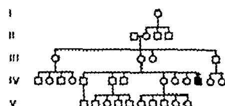
FAMILY 182



Family 182 Haemophilia A severe form

IV 1 (I F) Born 1938 First symptom of haemophilia at 9 months (postoperative bleeding) Repeated haemarthroses in all main joints Impaired function of knee joints Hospitalized several times for haemarthroses gastrointestinal bleedings and bleedings after tooth extractions He has received about 40 blood and plasma transfusions He attended a school for vocational training Present occupation typographer

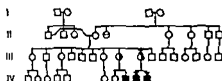
FAMILY 183



Family 183 Haemophilia B severe form

IV 11 (B A) Born 1947 First symptom of haemophilia at 18 months (intramuscular bleeding) Repeated bleedings in all main joints Impaired function of the left knee joint Hospitalized several times for haemarthroses and renal bleeding He has received about 40 blood or plasma transfusions Attends school In January 1965 achillotenotomy was performed under cover of a preparation of human haemophilia B factor

FAMILY 184

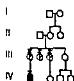


Family 184 Haemophilia A moderate form.

IV 9 (P B) Born 1955 First symptoms of haemophilia at 5 years (tooth extraction) Occasional bleeding in the ankle knee and shoulder joints which have not impaired the joint function Hospitalized a few times for haemarthroses and bleeding after tooth extraction He has received 5 blood transfusions He attends school

IV 10 (T B) Born 1958 First symptom of haemophilia at 1 year (intracranial bleeding) Since then paraplegia Recurrent haemarthroses most often in the knee joints Hospitalized several times for correction of paralytic pes equino-varus Right sided achillotenotomy in 1965 (Malmo) under cover of human fraction I—O

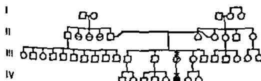
FAMILY 185



Family 185 Haemophilia B severe form

IV 1 (A E) Born 1954 First symptom of haemophilia at 1 year (bleeding at dentition) Repeated haemarthroses in the ankle knee and elbow joints which have not caused impaired function of the joints Hospitalized for bleeding from a wound bleeding after tooth extractions and nose bleeding He has received about 15 blood transfusions He attends school

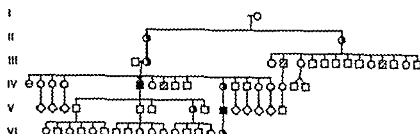
FAMILY 186



Family 186 Haemophilia A severe form

IV 6 (A M) Born 1960 First symptom of haemophilia at 9 months (postoperative bleeding) A few haemarthroses in the main joints Hospitalized for bleeding in connection with operation for hernia Treated with fraction I—O for operation of hernia and haemarthroses

FAMILY 187



Family 187 Haemophilia A mild form

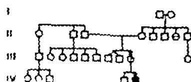
III 4 and III 12 are said to have bled easily after tooth extractions and from wounds Both are dead

IV 5 (J L) Born 1890 First symptom of haemophilia at 3 years (wound haemorrhage) Occasional haemarthroses in the knee joints which have not impaired joint function Hospitalized several times for nose bleedings bleedings after tooth extractions and surgery He has received about 70 blood and plasma transfusions Treated with fraction I—O for nose bleedings (1960) and for operation of hernia (1963) He attended school he did his military service but was discharged because of recurrent nose bleeding He worked as a farmlabourer and road worker but in 1948 he was granted a disability pension because of cardiosclerosis

IV 7 (J E L) Is said to have a bleeding tendency lives in Canada

V 9 (I S) Born 1915 First symptom of haemophilia at 25 years (bleeding after tooth extraction) No haemarthroses Hospitalized once for postoperative bleeding He attended school and did his military service Present occupation farmer

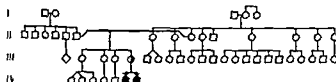
FAMILY 188



Family 188 Haemophilia A mild form

IV 5 (L P) Born 1919 First symptom of haemophilia at 2 years (wound bleeding) No haemarthroses Severe bleeding after tooth extractions and from wounds Several large haematomas No blood transfusions He attends school

FAMILY 189

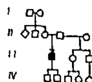


Family 189 Haemophilia A *severe form*

IV 6 (I O) Born 1958 First symptom of haemophilia at 7 months (subcutaneous haemor rhages) Recurrent haemarthroses in the ankle knee elbow and wrist joints *No impairment* of joint function In 1961 a large haematoma in the back The haemoglobin value decreased to 6 0 g/100 ml Blood transfusions on several *occasions*

IV 7 (S O) Born 1960 First symptom of *haemophilia at 1 year (subcutaneous hameor* rhages)

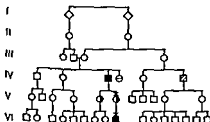
FAMILY 190



Family 190 Haemophilia A severe form

III 1 (M E) Born 1926 First symptom of haemophilia at 1 year (subcutaneous haemor rhage) Recurrent haemarthroses in all main joints Stiff right knee and impaired function *of other joints Hospitalized several times for* haemarthroses renal bleeding and bleeding af ter tooth extractions and trauma. He has had repeated episodes of severe melaena (haemoglobin values about 2 8 g/100 ml) Roentgenography of stomach revealed nothing remark able He has received about 150 blood trans *fus ons Treated with fraction I—O for gastro*intestinal bleeding (1961) haematomas and bleedings from tonsils (1961) He attended school he was exempted from military service and got ordinary vocational training at a school of commerce Present occupation businessman

FAMILY 191

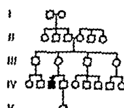


Family 191 Haemophilia A mild form

IV 3 (J Z) Born 1895 died 1959 of myocardial infarction He bled easily after tooth extractions and wounds

VI 9 (J E C) Born 1953 First symptom of haemophilia at 2 years (bleeding from a wound in the tongue) No haemarthroses Hospitalized occasionally for bleeding after tooth extractions and from wounds He attends school

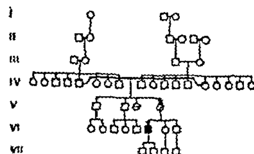
FAMILY 192



FAMILY 193



FAMILY 194



Family 192 Haemophilia A moderate form

IV 3 (M L) Born 1918 First symptom of haemophilia at 7 years (bleeding after tooth extraction) Haemarthroses 4 times in the right knee joint *Hospitalized 7 times for bleeding after tooth extraction haemarthroses and renal* bleedings He has received 8 blood and plasma transfusions He attended school and has served in the army as an officer Present occupation staff manager

Family 193 Haemophilia A mild form

II 1 (G J) Born 1873 died 1944 of intra cranial bleeding He always bled easily after *tooth extractions and trauma*

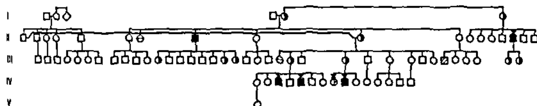
IV 3 (S T) Born 1936 First symptom of *haemophilia at 4 years (bleeding from a* wound) No haemarthroses He has had exces sive bleeding after tooth extractions and from wounds but has not required hospitalization or blood therapy He attended school and was *exempted from military service Present occupa* tion foreman

IV 4 (P G) Born 1943 First symptom of haemophilia at 7 years (bleeding after tooth extraction) Haemarthroses 2—3 times in the right knee joint in connection with cross country runs In 1961 he was hospitalized after a traffic accident He had sustained a fracture of the right femoral neck and several flesh wounds from which he bled profusely This excessive bleeding led to the diagnosis of his disease Healing of the fracture was retarded by complicating bleedings He received 7 blood transfusions He could attend school He was exempted from military service He is now at college

Family 194 Haemophilia A mild form

VI 6 (A A) Born 1922 First symptom of haemophilia at 1 year (bleeding after a wound *in the tongue*) Occasional haemarthroses in the right knee joint Slightly impaired function of both knee joints owing to rheumatoid arthritis Recurrent bleedings in the muscles *Hospi* talized several times because of gastrointestinal and renal bleedings and retroperitoneal haema toma and has received about 25 blood and plasma transfusions Treated with fraction I—O for tooth extraction (1961) Attended school Exempted from military service Present occu pation engineer

FAMILY 195



Family 195 Haemophilia A mild form

II 8 (K H) Born 1877 Treated several times in hospital for gastrointestinal bleeding He has always bled easily from wounds and after tooth extractions

II 16 (N I) Born 1876 died 1962 of post operative bleeding Treated several times in hospital for haematuria and postoperative bleeding after prostatectomy and collum femoris fracture

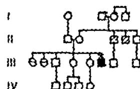
III 32 (T B) He is said to bleed easily from wounds and after tooth extractions

IV 3 (F R B) Born 1940 First symptom of haemophilia at 21 years (postoperative bleeding after tonsillectomy) No haemarthroses He has had excessive nose bleedings Hospitalized once for bleeding after tonsillectomy and received 11 blood transfusions He attended school and did his military service He is manual worker but is studying to get lighter work

IV 5 (R B) Born 1946 First symptom of haemophilia at 11 years (bleeding after tooth extraction) No haemarthroses or hospitalization He attended school Exempted from military service He is receiving vocational training as a clerk

IV 9 (K P) Born 1945 First symptom of haemophilia at 16 years (postoperative bleeding after tonsillectomy) No haemarthroses Hospitalized once for bleeding after tonsillectomy but did not require blood transfusions He attended school Exempted from military service He is receiving vocational training as a clerk

FAMILY 202



Family 202 Haemophilia B mild form.

II 3 (A J) Born 1876 He has had profuse bleedings after tooth extractions

II 4 (J S) Born 1878 He has had profuse bleedings after tooth extractions

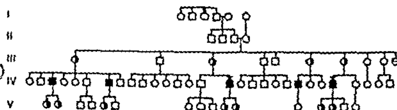
III 6 (E S) Born 1919 First symptom of haemophilia at 6 years (bleeding after tooth extraction) No haemarthroses Recurrent intra muscular bleedings after slight trauma Hospitalized a few times for bleedings after tooth extractions and has received one blood transfusion He attended school he did his military service and took a university degree (Bachelor of Economics) Present occupation managing director

Family 203 Haemophilia A mild form

It is not possible to get any information about the family because the patient was adopted and does not know his parents

(K S) Born 1919 First symptom of haemophilia at 16 years (postoperative bleeding after tonsillectomy) Haemarthroses once in the right knee after trauma which has caused impaired function of the joint Prolonged bleeding after tooth extractions and after wounds Hospitalized a few times for bleedings after trauma and gastrointestinal bleeding and given about 10 blood transfusions He attended school After 4 months military service he was discharged because of his bleeding tendency Present occupation unskilled labourer

FAMILY 204



Family 204 Haemophilia A mild form

IV 3 (S D) Born 1918 died 1957 of intra cranial haemorrhage He bled easily after tooth extraction and from wounds

IV 7 (R D) Born 1929 First symptom of haemophilia at 21 years (postoperative bleeding

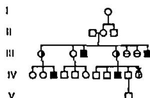
after tonsillectomy) No haemarthroses Hospitalized a few times because of bleeding after tooth extractions and after tonsillectomy Has received 2 blood transfusions He attended school and did his military service Present occupation consultant

IV 16 (E G) Born 1918 First symptom of haemophilia at 18 years (postoperative bleeding) No haemarthroses In connection with appendectomy and operation for hernia he bled heavily and required several blood transfusions Hospitalized several times for gastrointestinal and renal bleeding and bleeding after tooth extractions He has received about 25 blood and plasma transfusions In 1964 tooth extractions in Malmo under cover of AHF No bleeding complications He attended school he was exempted from military service because of asthma Present occupation mechanic

IV 22 (H G B) Born 1938 First symptom of haemophilia at 25 years (bleeding after tooth extraction) No haemarthroses or hospitalizations He attended school and did his military service Present occupation businessman

IV 25 (A G) Born 1925 First symptom of haemophilia at 10 years (prolonged nose bleeding) No haemarthroses Hospitalized several times for renal bleeding and bleedings after tooth extractions and minor surgery He has received about 5 blood transfusions He attended school and did his military service Present occupation radio operator

FAMILY 205



Family 205 Haemophilia A severe form

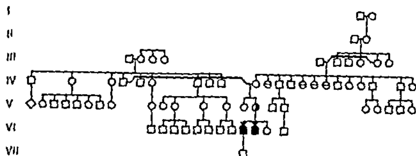
III 3 (N J) Born 1890 died 1917 of internal bleeding He had haemarthroses and had difficulty in walking

III 7 (J I) Born 1899 died 1923 of bleeding He had haemarthroses

IV 3 (H J) Born 1918 died 1922 of internal bleeding

IV 9 (E A) Born 1919 died 1926 of tetanus First symptom of haemophilia at 2 months (subcutaneous haemorrhages) Repeated haemarthroses intramuscular and nose bleedings Received one blood transfusion from his mother

FAMILY 206

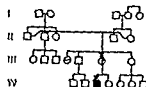


Family 206 Haemophilia A mild form

VI 9 (L E) Born 1938 First symptom of haemophilia at 23 years (bleeding after tooth extraction) No haemarthroses or hospitalization Prolonged bleeding after tooth extractions and abrasio He attended school and did his military service Present occupation electrician

VI 10 (K E) Born 1944 First symptom of haemophilia at 5 years (bleeding after tooth extraction) Occasional haemarthroses in ankle knee and hip joints after trauma Hospitalized for bleeding after tooth extraction and haemarthroses Has received 2 blood transfusions He attended school but was exempted from military service Present occupation electrician

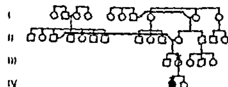
FAMILY 207



Family 207 Haemophilia A severe form

IV 3 (L G K) Born 1959 First symptom of haemophilia at 1 year (bleeding after puncture for blood test) Haemarthroses several times in different joints mainly knee joints and ankle joints but hitherto no impaired joint function Several episodes of large subcutaneous and intramuscular haematomas Repeated hospitalizations and has received about 10 blood transfusions Treated with fraction I—O for haemarthroses

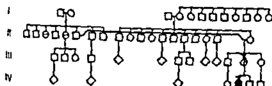
FAMILY 208



Family 208 Haemophilia A moderate form

IV 1 (P S) Born 1960 First symptom of haemophilia at 14 months (prolonged bleeding from a wound in the tongue) Haemarthroses several times in the knee hip and elbow joints but hitherto no impaired joint function Hospitalized for profuse bleeding after wounds in the tongue episodes of haemarthroses and large intramuscular haematomas He has received several blood transfusions and AHF on 3 occasions

FAMILY 209



Family 209 Haemophilia A severe form

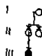
IV 3 (B A A) Born 1961 First symptom of haemophilia at 3 months (bleeding after venipuncture) Hospitalized for intracranial bleeding and haemarthroses Has received 5 blood transfusions Treated with fraction I—O for bleeding after venipuncture in the groin (1961)

Family 210 Haemophilia A severe form

Information about the family unavailable It is only known that the patient is the only child and has no relatives with a bleeding tendency

(L G L) Born 1936 First symptom of haemophilia at 1 year (subcutaneous bleedings) Recurrent haemarthroses in all main joints which have impaired function of the ankle knee and elbow joints Hospitalized several times for haemarthroses nose bleeding bleeding after tooth extractions and fracture of tibia gastro intestinal bleeding Has received about 100 blood transfusions Treated with fraction I—O for fractures after traffic accident (196?) He attended school Exempted from military service Present occupation clerk

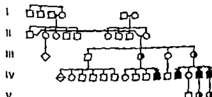
FAMILY 211



Family 211 Haemophilia A severe form

III 1 (G G) Born 1934 died 1956 of internal bleeding He had subcutaneous bleedings from early age

FAMILY 212



Family 212 Haemophilia A mild form

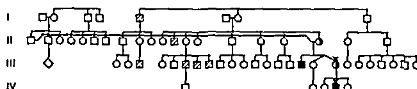
IV 9 (B L) Born 1910 First symptom of haemophilia at 8 years (bleeding after tooth extraction) A few times haemarthroses after trauma in the ankle and knee joint which have not impaired function of the joints Hospitalized several times for bleeding after tooth extractions profuse wound bleeding and haematuria Has received 2 blood transfusions He attended school Exempted from military service Present occupation taxi driver

IV 11 (L I) Born 1901 *First symptom of* haemophilia at 30 years (bleeding after tooth extraction) No haemarthroses Hospitalized *once for postoperative bleeding after operation* for hernia and received 4 blood transfusions. He attended school and he did his military *service Present occupation furrier*

IV 13 (B L) Born 1910 First symptom of haemophilia at 21 years (bleeding after tooth extraction) No haemarthroses Hospitalized twice because of bleedings after tooth extractions and has been given 4 blood transfusions He attended school and he did his military service Present occupation furrier

IV 14 (E L) Born 1920 First symptom of haemophilia at 13 years (bleeding after tooth extraction) Haemarthroses once in the knee *joint after trauma* Hospitalized twice for haemarthroses and bleeding after tooth extraction He attended school Exempted from military *service Present occupation* workshop assistant

FAMILY 213



Family 213 Haemophilia A severe form

I 5 (I R) Born 1858 died 1912 Is said to have had bleeding tendency

II 12 (T M) Born 1883 died 1913 Is said to have bled easily

III 3 (J M) Born 1920 Is said to bleed easily

III 6 III 7 III 8 (O J A J F J) Born 1932 1934 and 1939 Are said to bleed easily All these probable haemophiliacs lived or live in Norway

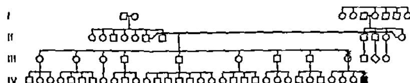
III 16 (O T) Born 1928 He bleeds easily *from wounds and has had repeated haemar*throses in main joints

IV 4 (L E H) Born 1953 First symptom of haemophilia at 5 months (bleeding from a wound in the tongue) Repeated haemarthroses in all main joints A marked deformity had developed in the left knee joint Hospitalized several times because of haemarthroses Often received blood and plasma transfusions In August 1963 a flexion defect in the left knee joint was corrected in Malmo under cover of AHF Treated with AHF for retroperitoneal bleedings and haematuria (1964) He attends school but is exempted from gymnastics

Family 214 Haemophilia B mild form.
Information about the family unavailable

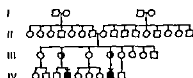
(J J) Born 1942 First symptom of haemophilia at 20 years (postoperative bleeding) No haemarthroses Hospitalized once for bleeding after traumatic injury in the shoulder and received 5 blood transfusions He attended school and did his military service Present occupation sheet metal worker

FAMILY 215



Family 215 Haemophilia B severe form
IV 32 (S P) Born 1957 First symptom of haemophilia at 4 months (subcutaneous haemorrhage) Repeated haemarthroses in the ankle *and knee joints* which have not impaired joint function Hospitalized a few times because of *haemarthroses bleeding from* wounds and subcutaneous and intramuscular bleedings Has received about 20 blood transfusions

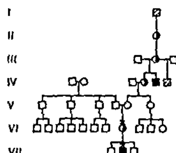
FAMILY 216



Family 216 Haemophilia A mild form
IV 4 (I E) Born 1953 First symptom of haemophilia at 10 years (bleeding after tooth extraction) No haemarthroses or hospitalizations He attends school

III 8 (S A V) Born 1937 First symptom of haemophilia at 5 years (bleeding after tooth extraction) No haemarthroses Often had nose bleeding profuse wound bleeding and large haematomas Hospitalized for postoperative bleeding after operation on knee joint and bleedings after tooth extractions He has received one blood transfusion He attended school and did his military service Present occupation iron worker

FAMILY 221

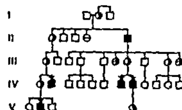


Family 221 Haemophilia B mild form

IV 5 (G F) Born 1912 died 1935 of retroperitoneal bleeding He always bled easily after wounds and tooth extractions

VII 2 (T H) Born 1957 First symptom of haemophilia at 4 years He then bled profusely after abrasio and required blood transfusions At 5 years he sustained a blow with a spade against the big toe of the left foot The nail loosened and the toe bled continuously for 10 days The haemoglobin decreased to 5 8 g/100 ml and blood transfusions had to be given He also had had several large haematomas No joint bleedings In 1963 four teeth were extracted under cover of plasma transfusions No bleeding complications He attends school

FAMILY 222



Family 222 Haemophilia A mild form

II 5 (E K) Born 1867 died 1937 of intra cranial bleeding
He bled easily from wounds and after tooth extractions

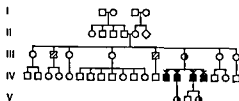
IV 2 (B J) Born 1936 First symptom of haemophilia at 11 years (bleeding after tooth extraction) No haemarthroses Hospitalized because of bleeding from a wound He attended school did his military service Present occupation farmer

IV 7 (M N) Born 1930 First symptom of haemophilia at 5 years (excessive bleeding from a wound) Haemarthrosis once in a knee joint after trauma Hospitalized for postoperative bleeding after operation for hernia and bleeding after tooth extractions He has received 12 blood transfusions He attended school but was exempted from military service Present occupation farmer

IV 8 (Y N) Born 1931 First symptom of haemophilia at 24 years (bleeding after tooth extraction) Occasional haemarthroses in the left ankle and knee joint after light trauma Hospitalized for bleedings after tooth extractions and haemarthroses Has received about 30 blood and plasma transfusions He attended school and did his military service Present occupation farmer

V 2 (J R) Born 1958 First symptom of haemophilia at 5 years (bleeding after tooth extraction) Once after slight trauma he had haemarthroses in the knee joint which needed hospitalization No blood transfusions Treated with fraction I—O for tooth extraction

FAMILY 223



Family 223 Haemophilia A mild form

III 2 (N W) Born 1900 died 1947 of myocardial infarction He had frequently had nose bleeding and bleeding after tooth extractions

III 5 (A W) Born 1906 He has had prolonged bleedings after tooth extractions

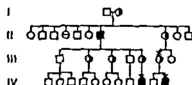
IV 14 (H N) Born 1933 First symptom of haemophilia at 25 years (bleeding after tooth extraction) No haemarthroses Hospitalized because of bleedings after tooth extraction and postoperati e bleeding after a knee operation He attended school and did his military service Present occupation pianotuner

IV 15 (G N) Born 1935 First symptom of haemophilia at 17 years (bleeding after tooth extraction) No haemarthroses or hospitalizations He attended school and did his military service Present occupation clerk

IV 16 (R N) Born 1937 First symptom of haemophilia at 10 years (bleeding after tooth extraction) No haemarthroses or hospitalizations He attended school and did his military service Present occupation supervisor

IV 17 (C H N) Born 1946 First sympto haemophilia at 7 years (prolonged nose bl ings) No haemarthroses or hospitalizati also has cerebral palsy He attended sch is now receiving vocational trai ing

FAMILY 224



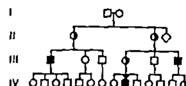
Family 224 Haemophilia A mild form

II 7 (E F G) Born 1900 He bleeds easily after wounds and tooth extractions

IV 9 (L G T) Born 1960 First symptom of haemophilia at 2 years (subcutaneous haemorrhage) Hospitalized once for bleeding from a wound Has received 2 blood transfusions

IV 11 (T O) Born 1959 First symptom of haemophilia at 4 years (bleeding after tooth extraction) No haemarthroses Hospitalized once because of bleeding after tooth extraction Has received one blood transfusion

FAMILY 225



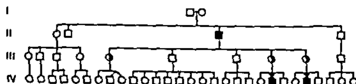
Family 225 Haemophilia A mild form

III 1 (O A) Born 1910 He bleeds easily after tooth extractions and from wounds No haemarthroses and never hospitalized

III 6 (K L) Born 1928 He bleeds easily after tooth extractions No haemarthroses and never hospitalized

IV 9 (J O L) Born 1952 First symptom of haemophilia at 10 years (postoperative bleeding after abrasio) No haemarthroses Prolonged bleeding after tooth extraction Hospitalized because of postoperative bleeding no blood transfusions He attends school

FAMILY 226



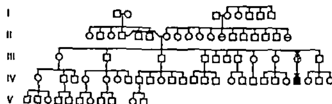
Family 226 Haemophilia A mild form

II 3 (F K) Born 1893 died 1963 of postoperative bleeding after operation on prostate He bled easily after tooth extractions

IV 22 (K S) Born 1949 First symptom of haemophilia at 10 years (prolonged bleeding from a wound) No haemarthroses and never hospitalized He attends school

IV 25 (R.W.) Born 1950 First symptom of haemophilia at 11 years (bleeding after tooth extraction) No haemarthroses or hospitalizations He attends school

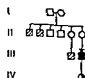
FAMILY 227



Family 227 Haemophilia A severe form

IV 27 (M.L.) Born 1961 First symptom of haemophilia at 7 months (subcutaneous bleedings) *Haemarthroses a few times in the ankle* and knee joints Hospitalized because of bleedings from wounds and intramuscular bleedings Has received 5 blood transfusions Treated with fraction I—O for bleeding after venipuncture

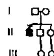
FAMILY 228



Family 228 Haemophilia B mild form

III 2 (J.K.) Born 1938 First symptoms of haemophilia at 14 years in connection with appendectomy The postoperative course was complicated by severe bleeding and the required several blood transfusions In 1961 and 1963 he was hospitalized for bleeding after tooth extractions and after gastrointestinal *bleeding After trauma he developed* large haematomas No joint bleedings He attended school but was exempted from military service Present occupation punch card operator He plays football

FAMILY 229



Family 229 Haemophilia B mild form

II 1 (J.H.) Born 1934 First symptom of haemophilia at 25 years (postoperative bleeding after tonsillectomy) Haemarthroses in the ankle joint after trauma. Hospitalized because of postoperative bleeding and bleeding after tooth extractions Has received about 20 blood and plasma transfusions He attended school and did *his military service* Present occupation clerk

Family 230 Haemophilia A mild form

No known bleeding tendency among relatives (the patient is from Russia)

(V N) Born 1913 First symptom of haemophilia at 5 years (bleeding after tooth extraction) Haemarthroses once in the ankle joint after trauma Hospitalized because of haematuria bleeding after tooth extractions Has received about 10 blood transfusions He attended school and did his military service Present occupation electrician

Table 1 Survey of the present case material

Fam. No.	Coordinate No.	Type of haemophilia	Case	Year of birth	Heredity None=0 Pos.=+	Mth/yr of invest.	Coagulation time min	Bleeding time (Duke) min	Platelets per mm	AHF % of normal	B-factor % of normal	Circulating anticoagulant	Prothrombin consumption residual %	P&P (prothrombin + VII)	Factor V % of normal	Fibrinogen g/100 ml
4	VI 3	A (severe)	C.H.N.	1957	+	10/57	16 (capillary)	2	190 000	< *1*	—	0	—	95		
						4/63	> 60			*0.6*	123	0	—	160	92	0.48
6	III 9	A (mild)	H.A.	1899	+	11/58	11	3	—	*4*	100	0	127	68	200	0.15
						9/62				*5*	73					
9	IV 2	A (moderate)	S.M.	1943	+	8/58	73	11	290 000	*1—2*	110	0	136	66	120	0.32
						1/62	60			*1*						
						9/63	60			*1*						
						9/64	> 60			*1*						
11	Son of IV 6	B (moderate)	K.D.	1962	+	6/63	15	2	504 000	190	*3*	0	26	101	107	0.32
22	VI 2	A (severe)	B.I.	1948	+	6/59	—	4	—	*1.8*	90	0	—	96	100	0.13
	VI 6	A (severe)	R.K.	1940	+	6/59	115	5	220 000	*0.5*	98	0	88	83	100	0.42
	VI 10	A (severe)	F.K.	1951	+	6/59	100	4	—	*0.5—2*	93	0	147	78	105	0.49
28	VI 5	A (severe)	A.K.	1960	+	5/62	75	1		*2*	55	0	—	77	105	0.34
	Son of VI 2	A (severe)	M.J.	1963	+	9/64	46	10		*0.3*	78	0	—	89	143	0.17
31	VI 4	B (severe)	S.N.	1961	+	2/62	30	7	472 000	125	*0*	0	—	99	107	0.29
	VI 5	B (severe)	H.N.	1962	+	8/64	25	2	284 000	100	< *1*	0	100	71	99	0.22
41	III 10	B (mild)	K.R.O.	1904	+	5/63	9	2	—	66	*6*	0	—	125	108	0.31
	IV 13	B (mild)	K.C.O.	1916	+	5/63	11	2	—	110	*10*	0	—	108	113	0.40
42	Son of V [illegible]	A (severe)	I.O.C.	1964	+	10/64	[illegible]	—		< *1*	[illegible]					

57	V 1	A (severe)	H B	1917	+	7/61	20	4		*1 3*	91	0	77	71	123	0 21
71	III 7	B (mild)	J A	1884	+	5/63	—	3		*113*	*10*	0	—	74	110	0 20
						6/63	10				*8*					
73	IV 22	A (severe)	A J	1915 †1964	+	1/63	> 60	3	402 000	< *1*	100	0	110	84	132	0 51
77	IV 4	A (severe)	S S	1955	+	1/61	> 60	1	500 000	< *1*	68	0	43	88	165	0 33
83	IV 25	A (severe)	P O	1946	0	1/63	> 60	3	342 000	< *1*	78	0	147	74	98	0 31
93	III 15	A (mild)	C R	1938	+	7/61	20	2	260 000	*11*	110	0	33	126	155	0 0
94	III 10	A (mild)	K K	1904	+	12/63	11	6	—	*10*	*88*					
100	III 3	B (severe)	B W	1914	+	11/61	60	2	n	107	< *1*	0	—	69	150	—
	IV 1	B (severe)	B A	1918	+	10/61	60	8	352 000	73	< *1*	0	80	49	114	0 15
109	IV 3	B (moderate)	G A	1913	+	8/62	19	2	242 000	80	*2*	0	43	106	130	0 49
	IV 6	B (moderate)	J A	1953 †1963	+	5/63				50	*3*	0		70	56	—
114	II 7	A (severe)	T J	1937	+	10/62	21			1 5	133	0	—	74	71	0 44
122	IV 4	A (mild)	R B	1915	+	11/63	12	2	—	*16*	61	0	—	89	163	0 33
124	III 2	B (moderate)	F H	1930	0	6/58	12	3	161 000	86	*0 5—2*	0	*100*	67	113	
						1/64	12			98	*1 4*	0	—	87	115	0 39
126	IV 1	A (mild)	I J	1957	+	1/59	12	3	—	*6*	145	0	66	85	60	0 25
						3/61				*5*						
133	III 11	A (moderate)	S B	1915	+	11/58	17	5	—	*1—5*	58	0	31	65	98	0 30
						3/59				*4*						
	IV 4	A (moderate)	S G K	1928	+	8/62	17	2		*2 5*		0	91	109	110	0 28
						9/62	18			*3 9*	110	0				
	IV 6	A (moderate)	A K	1934	+	1/64	17	6		*3 3*	109	0	—	132	123	0 31
	IV 15	A (moderate)	N K	1919	+	6/64	9	4		*7*	258	0	—	100	98	0 26
						6/64	9			*7*	175					
144	IV 1	A (moderate)	J F K	1941	+	8/61	26	4	250 000	*1 7*	83	0	70	115	107	0 30
	IV 4	A (moderate)	B N	1939	+	9/62	40	1	262 000	*1 3*	113	0	113	140	139	0 60

Fam. No.	Coordinate No.	Type of haemophilia	Case	Year of birth	Heredity None = 0 Yes = +	Mth/yr of onset	Coagulation time min	Bleeding time (Duke) min	Platelets per mm³	AHF % of normal	B factor % of normal	Circulating anticoagulant	Prothrombin consumption residual %	P&P (prothrombin + f VII) %	Factor V % of normal	Fibrinogen g/100 ml
145	II 7	A (mild)	A H	1927	+	2/61	13	1	—	78	103	0	—	77	105	—
						11/63	13			21						
	II 6	A (mild)	H H	1912	+	2/61	19	2	—	19	55	0	—	59	96	—
						4/64	16			23						
	III 4	A (mild)	K H	1953	+	1/61	12	1	200 000	18	80	0	8	110	110	0·36
						11/62	13			21						
	III 5	A (mild)	R H	1956	+	1/61	14	3	200 000	15	95	0	93	66	75	0·41
						3/62	17			20						
147	IV 6	A (severe)	K S	1961 †1963	+	5/62	> 60	3	n	< 1	185	0	> 100	93	147	—
148	IV 1	A (moderate)	P W	1956	+	3/61	—	—		1·5	90	0	105	90	85	0·38
151	IV 1	B (severe)	T K	1959	+	11/62	> 60	5	—	91	0	0	—	81	94	0·33
153	III 6	B (moderate)	B F	1915	0	10/62	40	3	242 000	135	1	0	10	91	140	0·31
						10/62					1					
158	IV 7	A (severe)	S K	1939	+	4/62	> 60	3	352 000	0·1	100	0	61	80	90	0·51
159	V 9	A (severe)	R H	1952	+	3/63	> 60	5	n	0	69	0	—	114	69	0·28
						10/64	> 60			< 1						
160	IV 3	A (moderate)	L E	1931	+	1/61	14	3		2·5	103	0	71	105	110	0·22
	IV 5	A (moderate)	P F	1935	+	1/61	17	3		2·7	78	0	86	105	120	0·29
166	IV 10	A (moderate)	L R O	1892	+	5/62	20	3	224 000	3	150	0	85	112	190	0·71
169	III 2	A (moderate)	B S	1909	0	10/61	60	1	276 000	1·2	112	0	100	62	114	0·32
170	IV 1	A (moderate)	L W	1913	0	9/63	11	—	—	1	115	0	—	128	103	0·13
171	IV 1	B (moderate)	T A	1911	0	10/60	—	2	—	115	3	0	53	132	—	0·30
172	III 4	A (severe)	J B	1908	+	9/60	> 60	3	214 000	0·1	123	0	80	120	150	0·36

174	III	27	A (mild)	B S	1928	+	2/61	15			2	—	0	11	76	85	0 34
	III	28	A (mild)	D S	1935	+	7/64	—	—	—	12	82	0	—	128	87	0 13
175	IV	10	A (severe)	I W	1956	+	9/62	> 60	5	410 000	< 1	93	0	70	114	155	0 38
176	IV	14	B (severe)	L C L	1959	+	2/61	8			133	6 4	0	107	110	153	0 45
177	IV		B (mild)	B H	1930	+	12/60	15	4	192 000	90	12	0	41	61	130	0 37
							8/64					10					
	IV	8	B (mild)	S O H	1935	+	10 60	17	2	304 000	64	6	0	83	78	73	0 23
	IV	9	B (mild)	A H	1938	+	11/60	17	3	180 000	60	12	0	61	83	132	0 30
	V	8	B (mild)	T R S	1951	+	3/63	23	3	296 000	95	9	0	19	108	124	0 33
178	IV	8	A (moderate)	M I	1938	+	2/60	31	3	368 000	9	55	0	180	190	133	0 56
179	IV	10	A (severe)	C I	1945	0	10/60	—	3	—	< 1	93	0	105	—	—	—
180	IV	1	B (moderate)	L O K	1939	+	4/62	31	2	248 000	102	1 4	0	—	65	106	0 39
	IV	2	B (moderate)	G K	1943	+	2/61	13	1	—	65	1 4	0	35	93	66	0 28
181	IV	8	A (severe)	H W	1958	+	4/61	52	6	351 000	0 1	100	0	157	106	111	0 37
							8/63	60			0 1						
							1/65				0 1						
182	IV	1	A (severe)	I F	1939	0	5/61	60	2	344 000	< 1	95	0	100	59	139	0 28
183	IV	11	B (severe)	B A	1947	0	5/61	28	2	322 000	119	< 1	0	92	55	105	0 45
							1/64	60				< 1	0		59	100	
184	IV	9	A (moderate)	P B	1955	+	12/60	17	2		26	14	0	75	102	113	0 26
	IV	10	A (moderate)	T B	1959	+	11/62	—	1	284 000	< 15	58	0	76	88	150	
							4/65	26			4						
							5/65				3						
185	IV	1	B (severe)	A E	1954	+	6/64	15	4	—	74	0 5	0	pitol	105	107	0 30
186	IV	6	A (severe)	A M	1960	+	6/61	—	5		0 4	89	0	73	133	160	0 53
187	IV	5	A (mild)	J L	1890	+	8/60	8	2	185 000	23			80	92		
							1/63				16						
189	IV	5	A (mild)	L P	1949	+	7/61	19	4	314 000	8	90	0	100	110	118	0 35

Fam No	Coordinate No	Type of haemophilia	Case	Year of birth	Heredity None = 0 Pos = +	Month/yr of invest	Coagulation time min	Bleeding time (Duke) min	Platelets per mm³	AHF % of normal	B-factor % of normal	Circulating anticoagulant	Prothrombin consumption residual %	P&P (prothrombin + (VII)) %	Factor V % of normal	Fibrinogen g/100 ml
219	IV 10	A (mild)	E P	1933	0	2/58	10	3—5	–	36	105	0	—	78	70	
						1/63	8	6		39	63	0		110	135	0 22
						2/65	6			40						
220	II 3	A mild	F N	1908	+	7/63	12		34 000	21	93	0		60	71	0 46
				†1963		7/63				15						
	III 5	A (mild)	A H	1928	+	6/63	19	2	276 000	11	118	0	27	110	94	0 36
						6/64				12						
	III 8	A (mild)	S A A	1937	+	6/63	19	3	272 000	11	118	0	57	81	93	0 38
						6/63				9						
221	VII 2	B (mild)	T H	1957	+	7/63	16	3	272 000	177	14	0	12	114	119	0 35
222	IV 9	A (mild)	B J	1936	+	4/64	8	6	n	6	84	0	patol	93	101	0 22
	IV 7	A (mild)	M N	1930	+	6/63	8	2	—	5	88	0	—	91	85	0 18
	IV 8	A (mild)	A N	1931	+	4/63	9	1	195 000	6	56	0	—	75	63	0 26
	V 2	A (mild)	J R	1958	+	4/64	8	2	n	7	109	0	patol	102	103	—
223	IV 14	A (mild)	H N	1933	+	5/63	15	4		21	66	0	—	98	135	0 78
						6/63	7			9						
						10/63				12						
	IV 15	A (mild)	G N	1935	+	2/63	13	4	—	9	67	0	—	97	93	0 21
	IV 16	A (mild)	R N	1937	+	8/63	6	3	—	17	72	0	–	85	108	0 72
						10/63				10						
	IV 17	A (mild)	C N	1946	+	8/63	12	6	—	14	66	0	—	84	115	0 21
						10/63				14						
224	IV 1	A (mild)	L C T	1960	+	5/63	10	3	240 000	5	93	0	—	99	113	0 24
	IV 11	A (mild)	L O	1959	+	10/63	6	3	218 000	14	89	0	—	102	129	0 32
225	IV 9	A (mild)	J O L	1952	+	11/63	10	1	250 000	35	113	0	—	89	102	0 30
						12/63				18						

226	IV	22	A (mild)	K S	1949	+	10/63	11	4		*25*	—	—	—	83	—	0 25
	IV	25	A (mild)	R W	1950	+	11/63	10	1		*23*	96	—	—	84	69	0 23
227	IV	22	A (severe)	M L	1961	+	12/64	—	—		*0 5*						0 25
228	III	2	B (mild)	J K	1938	+	2/64	12	3	218 000	87	*21*	0	75	91	112	0 31
229	II	1	B (mild)	J H	1934	0	12/63	22	5	298 000	115	*16*	0	26	102	120	0 43
230	—		A (mild)	V N	1913	?	10/63	9	3	—	*10*	78	0	—	99	82	0 29

Blood sampling not adequate
* It has not been possible to check the value
The test performed on a mailed blood sample
After blood transfusion
n=Normal value

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G DUNCAN MCPHERSON

Stable Calcium Isotopes as Tracers in Studies of Mineral Metabolism

Acta Orthopaedica S
Supplementum No 78

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM NO 78

From the Orthopaedic Research Laboratories (Head Goran C. H. Bauer M. D.)
of the Orthopaedic Clinic (Head Sophus von Rosen M. D.)
Malmo General Hospital University of Lund Malmo Sweden and
the Hospital for Special Surgery affiliated with the New York Hospital —
Cornell University Medical College New York City

Stable Calcium Isotopes as Tracers in Studies of Mineral Metabolism

BY G DUNCAN MCPHERSON

MUNKSGAARD COPENHAGEN 1965

PRINTED IN SWEDEN BY
BERLINGSKA BOKTRYCKERIET
LUND 196[illegible]

CONTENTS

CHAPTER IV

Estimation of the Exchangeable Calcium Pool in Children using ' Ca 62

General Introduction

The use of stable isotopic tracers in the study of biological systems has several advantages The system studied is not subjected to any radiation hazard Stable isotopes do not themselves decay and their distribution in the system studied and its changes with time may be followed by measurement of the abundance of the isotope in samples which are representative of the system

The availability of enriched stable calcium isotopes suggested their application as tracers of calcium kinetics Measurement of abundance of Ca and Ca is dependent upon precise determination of

1 the isotopic species by either mass spectrometry or neutron activation analysis and
2 the total amount of natural calcium in the sample studied

This communication describes an investigation of the methods for the use of stable calcium isotopes and the application of this non radioactive tracer technique to the determination of the exchangeable calcium pool in children

CHAPTER 1

Direct EDTA Titration of Calcium and Magnesium in Biological Samples

I INTRODUCTION

The refinement of isotope tracer techniques used in the study of calcium metabolism has focussed attention on the need for precise and reliable methods for determination of total calcium in a variety of biological samples. The large numbers of samples which may be accumulated in the course of tracer kinetic studies require as well that such methods be both simple and rapid to avoid overloading laboratory facilities.

Efforts to evaluate the significance of reported differences in specific activity of calcium isotopes between serum and urine led to a study of methods for determination of urine calcium (Medical Uses of Ca, Vienna 1962). Dissatisfaction with procedures existing at that time prompted this investigation of a precise method for determination of total calcium which could be applied to urine and solutions of bone tissue and feces ash as well as to serum.

The method had to be —

1. accurate over a wide range of concentrations
2. as precise when applied to samples as to standards
3. require little or no sample preparation
4. be applicable to biological samples of varying electrolyte composition without interference from other substances
5. be free from the subjective influence of the operator

A Determination of Total Calcium

1 Oxalate Precipitation

Methods involving the quantitative precipitation of calcium (Kramer and Tisdall 1921, Clark and Collip 1925, Fiske and Logan 1931) are subject to a system of errors which have been demonstrated by MacIntyre (1957) using Ca tracer techniques.

2 Flame Photometry

Flame photometric methods have proven useful in the routine clinical laboratory estimation of serum calcium but are subject to interference

from both sodium and phosphate when used to determine calcium in urine or other solutions of varying electrolyte composition Most flame photometry procedures involve a prior removal of protein (MacIntyre 1957) or precipitation of calcium as oxalate thus in some instances introducing the errors of the oxalate precipitation as well (Toribara *et al* 1957 Woollen and Walker 1959 Brandstein *et al* 1963 Loken *et al* 1963)

3 Atomic Absorption Spectrophotometry

This new technique has been applied to serum by Zettner and Seligson (1964) and to urine and serum by Sprague (1964) with a high degree of precision The standard curve is *non linear however necessitating* a series of standards Deproteinization of serum and dilution of urine in lanthanum solution are required

4 Colorimetry and Spectrophotometry

The introduction of metal indicating dyes and the later application of complexing or chelating agents to the titration of metal ions by Schwarzenbach *et al* (1946) have revolutionized this field of analytical chemistry Several reviews summarize progress in the application of these agents (Barnard *et al* 1957 Sadek and Reilley 1959 Reilley and Schmid 1959 Diehl and Ellingboe 1960)

Metallochromic indicators have been used in a variety of colorimetric and spectrophotometric methods for the direct determination of calcium and calcium plus magnesium (Young *et al* 1955 Yanigasawa 1955 Kingsley and Robnett 1957 Harper 1959 Kellerman and Dale 1960 Brush 1961) These methods demand strict control of procedure and usually require a complex series of reference standards to construct a standard absorbance or concentration curve each time the method is used Colorimetric calcium estimation has also been adapted to the Auto Analyzer (Boonstra and Jackson 1962) These methods have not been as widely used for total ion estimation as they have for the determination of free metal ion concentration in serum (Rose 1957) and urine (Nordin 1960) The estimation of total calcium in feces or tissue ash solutions is not feasible because of interference from other electrolytes in samples of such variable composition (Raaflaub 1956 Rose 1957)

5 *Chelometric Titration of Calcium*

The most widely used methods for estimation of total calcium and total calcium plus magnesium employ metal indicating dyes [murexide Eriochrome Blue SE Eriochrome Black T and many others—see Bar

The principle of magnesium determination as the difference between EDTA titration of calcium and calcium plus magnesium is well established. It remained only to select conditions such that calcium and magnesium could be titrated directly using the precise recorded end point detection method described for serum calcium by Copp (1963).

C. Principle of Direct EDTA Titration of Calcium and Magnesium in Biological Samples

Ethylenediaminetetraacetic acid (EDTA), like other chelating agents, is non-selective, combining with many di-, tri- and quadrivalent cations (Barnard *et al.* 1957). Selectivity for specific ion titrations is achieved by the use of masking agents and control of pH.

Above pH 9.0, calcium and magnesium combine with EDTA in a 1 to 1 stoichiometric relationship. At this pH level other cations such as Fe, Cu, Zn, Mn also combine with EDTA. These are masked from EDTA by addition of cyanide which forms more stable complexes with them than does EDTA.

At pH levels above 12.0, magnesium is removed from solution as the insoluble hydroxide $Mg(OH)_2$ which does not react with EDTA. Magnesium may thus be determined by the difference between titration of calcium plus magnesium at pH 10.1 and titration of calcium at pH 12.0 or higher.

Murexide gives a sharp end point for the calcium titration. Recently, a new indicator, Calmagite, has been applied to the calcium plus magnesium titration, giving a sharper end point than those previously in use.

In samples containing relatively high concentrations of phosphate, such as urine and bone tissue or feces ash, interference has been observed in the titration of total calcium (Horner 1955). At the high pH of the calcium titration, calcium phosphate complexes are formed. While EDTA will eventually remove all calcium from these complexes, the reaction proceeds slowly so that a titration performed too quickly will give a premature or poorly defined end point and a low value for total calcium.

In most EDTA titration procedures this interference has been avoided by *prior removal of phosphate from such samples by precipitation* (Horner 1955) and by ion exchange columns (Loss 1959). Bachra *et al.* (1958) found that citrate delays the formation of such calcium phosphate complexes. Citrate combines with ionic calcium, thus lowering the product of free calcium times phosphate below that critical for complex formation. EDTA, however, removes calcium readily from the citrate.

The procedure described here extends the semiautomatic spectro photometric EDTA titration of calcium in serum to the direct titration of calcium and calcium plus magnesium in serum urine and tissue bone or feces ash solutions Little sample preparation is required and the rapid precise quantitation of 0 10 or 0 20 ml aliquots is achieved by a semi automatic diluting pipet Addition of citrate to titrated aliquots prevents interference from phosphate

II MATERIALS AND METHODS

A Apparatus

The apparatus is shown in a block diagram in Figure 1

A Beckman B spectrophotometer was fitted with a holder supporting the titration cell a Pyrex test tube 15×100 mm so that the light path was just above the curved bottom of the tube A small 11/2—3 volt electric motor of the type used in models was incorporated in a light shielding wooden mixing head to spin a soft polyethylene tube with a flattened closed end at a rate adjusted by a rheostat to avoid vortex formation A constant speed pump Harvard Infusion Withdrawal Pump no 600 900 with an electro magnetic clutch supplied titrant at .250 ml/minute through a fine bore polyethylene tube led into the titrating solution through the mixing head Mixing and supply tubes ended just above the light path The output of the Beckman B was recorded as changing transmittance on a Sargent SRL recorder with a 25 MV range plug The recorder chart drive switch actuated the clutch of the titrant pump The chart speed was 2 inches per minute

The titration cell was stirred constantly as titrant was added from the constant flow buret coupled to the recorder drive and the changing transmittance or absorbance recorded as a line on the chart showed a sharp break at the end point The degree of precision was high because the extended intersecting lines drawn at the break were based upon a series of points (i e the record) rather than upon a few points as in manual titration methods Measurement of the distance along the chart from start to the end point reflected the volume of titrant and hence the Ca or Ca+Mg content of the sample

B Reagents

Reagents were of A R quality where possible Demineralized water was used for making solutions and for diluting samples Because of the ion exchange properties of glass reagents were stored in polyethylene bottles All glassware was acid washed and rinsed in distilled water

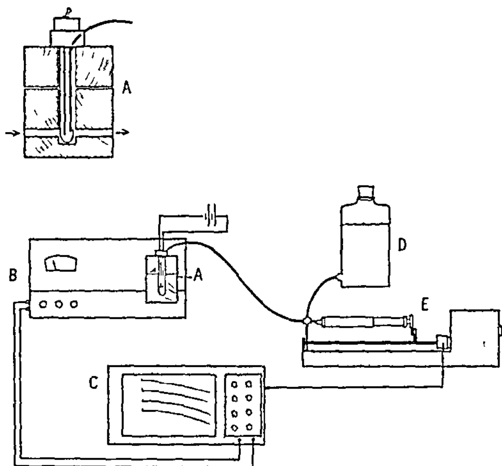


FIGURE 1 Apparatus for recorded titration of calcium and magnesium

A A wooden block holds the sample tube with its lower end in the light path of the spectrophotometer
A second block supports a small 1½ to 3 volt mixing motor which spins a soft polyethylene tube in the solution during the titration A second titrant delivery tube of fine bore polyethylene enters the sample tube beside the mixing tube
B Beckman B Spectrophotometer Transmittance is recorded as titration proceeds —Wavelength 450 is used
C Sargent SRI Recorder Transmittance on the Beckman B is recorded at a chart speed of 2 inches per minute
D EDTA 0.001 M titrant reservoir of polyethylene
E Harvard No 600—900 Constant Speed Infusion Pump
Delivery rate is .250 ml of titrant per minute using a 30 ml syringe Two way stopcock to reservoir is glass The titrant drive is started by an electromagnetic clutch controlled by the switch of the synchronous motor which drives the chart ensuring simultaneous start and stop of chart drive and titrant delivery

1 Calcium Standard 40 mg% and 10 mg%

1 000 Gm of Ca CO (Mallinckrodt Primary Standard) dried overnight at 105° C was dissolved in a minimum amount of 5N HCl and diluted to 1 litre water From this stock solution of 40 mg% Ca^{++} a working standard solution of 10 mg% Ca^{++} was made up as required

2 Magnesium Standard 100 mg% and 2 mg%

10 131 Gm of Magnesium sulfate MgSO 7H O was dissolved in water and diluted to 1 litre From this 100 mg% stock a 2 mg% Mg working standard was made up as required

From chemical equivalence the amount of EDTA needed to chelate 2 00 mg% Mg is 329 times the amount required to chelate the same volume of 10 0 mg% Ca Magnesium standard values can thus be determined from the titration of calcium standards alone

3 EDTA 0 01 and 0 001 M

3 723 Gm of di sodium ethylenediaminetetraacetic acid (Mallinckrodt) was dissolved in water and diluted to 1 litre From this stock 0 01 M EDTA *the titrant solution 0 001 M in water* was made up as required

4 Sodium Citrate 0 1 M

2 490 Gm of Na Citrate (Mallinckrodt) was dissolved in water and diluted to 1 litre

5 KCN 1 %

10 Gm of KCN (Mallinckrodt) was dissolved in water and diluted to 1 litre

6 NaOH 8 0 N

32 0 Gm of NaOH (Mallinckrodt) was dissolved in water and made up to 100 ml

7 NH Cl—NH_4OH Buffer

67 5 Gm NH Cl (Mallinckrodt) was dissolved in 570 ml of concentrated NH OH (DuPont) and diluted to 1 litre with water A 10 per cent solution of this stock buffer was made up as required to fill the reservoir of a diluting pipet used for the calcium plus magnesium titration

C Indicators

1 Calcium Indicator

0 100 Gm of Murexide (ammonium purpurate acid) (Matheson Coleman and Bell) was dissolved in water and diluted to 100 ml The solution was stable for 2—4 weeks at 5° C

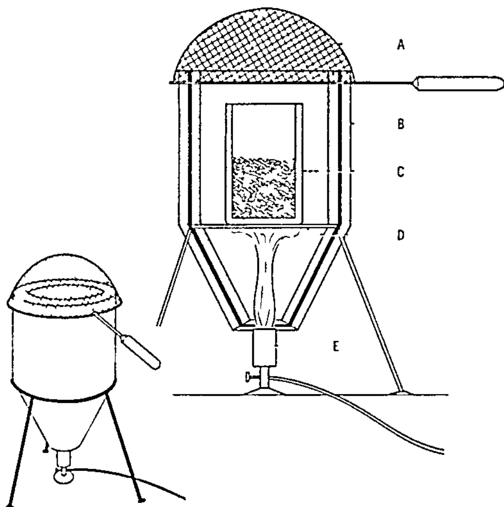


FIGURE 2 Incineration apparatus

A Screen cover of stainless steel (household strainer)
B Insulated chimney of asbestos on a steel cylinder
C Container for sample—Vycor or glazed porcelain
D Support rods of steel to hold container over flame
E Propane burner—industrial type

2 Calcium plus Magnesium Indicator

0 100 Gm of Calmagite (Aldrich Chemical Company Milwaukee Wisconsin) was dissolved in water and diluted to 100 ml The solution was stable for 1 month at room temperature

Na Citrate 0 1 M KCN 1 % NaOH 8 0 N and the indicator solutions were kept in polyethylene dropper bottles

D Sample Preparation

Sample aliquots were taken directly from serum urine and acid solutions of bone tissue or feces ash using an automatic diluting pipet (Seligson 1957)

A 0 20 ml aliquot was drawn up into the pipet and washed into the sample test tube with 4 ml of the titrating solution using water in the case of calcium, and NH_4Cl—NH_4OH buffer in the case of the calcium plus magnesium titration Two matched automatic pipets permitted precise quantitation of sample aliquots for both titrations independent of differences in viscosity between samples and standards

1 Serum Plasma and Cerebospinal Fluid

Aliquots were drawn directly from fresh samples If samples had to be kept for some hours they were transferred to polyethylene sample tubes and stored at 5° C

2 Urine Samples

All samples were acidified to pH 2—3 to dissolve any calcium complexes which might have precipitated Aliquots were then taken directly

3 Incineration Procedure for Bone Tissue and Feces Samples

Feces samples were collected on sheets of thin polyethylene which were then wrapped around the sample for storage in air tight standard 1 quart paint cans until analysis

The entire sample and its covering plastic were incinerated in a glazed porcelain or Vycor beaker of 500—800 ml capacity placed over a propane flame in an insulated chimney See Figure 2 This insulated chimney was modified from a gas and air fired apparatus described by Buchanan and Sampson (1962) to use a propane heat source A wide mouth burner was used at a gas pressure of 10 lbs per square inch

Products of combustion were burned completely in passage through the red hot steel mesh covering the chimney There was no odour but because of the heat generated an exhaust hood was used After burning for 10 to 15 minutes with an orange flame the sample was reduced to

a few ml's of soft grey white ash A new sample could be burned to ash on top of the first to combine several days collection The ash could be further reduced in volume by placing the beaker in a muffle furnace of 500° C for 3 hours

The small volume of the ash permitted radioactivity measurements to be made upon the ash of an entire period of collection The ash could then be dissolved in 5 N HCl and diluted appropriately for direct titration of total calcium and calcium plus magnesium in the presence of added citrate

Bone tissue or diet samples were incinerated in the same manner as feces samples

E Preparation of Aliquots for Titration

1 Calcium

a Using the automatic pipet 0 20 ml of sample or standard were washed into a 10×1 5 cm Pyrex test tube with 4 ml of water

b In the case of urine and bone tissue or feces ash solution 3 drops of 0 1 M Na Citrate were then added

c 1 drop 1 % KCN was added

d 2 drops 8N NaOH were added (4 drops were used if the aliquot had a very low pH)

e 2 drops indicator solution were added (Murexide 100 mg%)

2 Calcium+Magnesium

a Using the automatic pipet 0 20 ml of sample or standard were washed into a test tube with 4 0 ml of 10 % NH_4Cl—NH_4OH buffer solution

b In case of urine and bone tissue or feces ash solutions 3 drops of 0 1 M Na Citrate were added

c 1 drop 1 % KCN was added

d 2 drops indicator solution were added (Calmagite 100 mg%)

F Titration Procedure

The procedure was the same for all samples The test tube was placed in the holder and covered with the mixing head ensuring that both mixing tube and titrant delivery tube were in the solution The mixing motor was started At wavelength 480 mμ the slit width of the Beckman B was adjusted for 30 % transmittance at sensitivity 3 The recorder chart drive was started simultaneously actuating the titrant delivery pump The curve of changing transmittance showed a sharp break

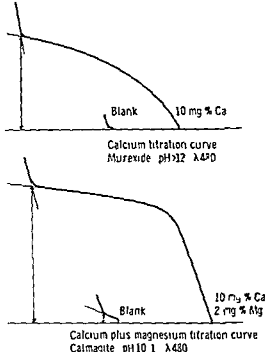


FIGURE 3
Typical calcium and calcium plus magnesium titration curves recorded as transmittance against time
Blank titrations are illustrated

which marked the end point—see Figure 3 The distance along the chart from the start to the end point was a measure of the volume of titrant and hence of the metal ion content of the titrated sample Blank values were determined for both titration and subtracted from both sample and standard values before they were compared

G Interpretation of Results

$$\text{Calcium in mg\%} = \frac{(\text{Ca sample—Ca blank})\ \text{mm}}{(\text{Ca standard—Ca blank})\ \text{mm}} \times 10$$

Magnesium in mg% =

$$= \frac{[(\text{Ca}+\text{Mg})\ \text{sample—}(\text{Ca}+\text{Mg})\ \text{blank}]\text{—}(\text{Ca sample—Ca blank})\ \text{mm}}{(\text{Ca standard—Ca blank}) \times 329\ \text{mm}} \times 2$$

III RESULTS

A Precision and Recovery Studies

1 *Titration Conditions*

Wavelength 480 mμ provided a sharp break in the transmittance curve for both titrations Typical curve patterns are shown in Figure 3 The absorption spectra of murexide and Calmagite are shown in Figure 4

The concentration of the $NH_4OH—NH_4Cl$ pH 10 1 buffer used in the calcium plus magnesium titration was adequate regardless of the initial pH of aliquots Four drops of 8 0 N NaOH similarly ensured pH above 12 5 when titrating acidified aliquots for calcium Excess NaOH did not affect the end point

The sensitivity of the titration required that blank values be subtracted from observed values The blank was due to traces of calcium and magnesium in water as well as in reagents used It was larger in the $NH_4OH—NH_4Cl$ buffer solution The blank value for the calcium titration corresponded to 0 20 μGm calcium per ml of titration solution

The mixing lag noted by Copp (1963) appeared actually to be the blank titration value Blank titration curves are shown in Figure 3

Using the chart speed titrant delivery rate and reagent concentration described the titration of a 0 20 ml aliquot of a 10 mg% solution of calcium required less than one minute It was quite feasible to run 40 to 50 calcium determinations per hour preparing aliquots during the time that the apparatus was automatically carrying out titrations

2 Standard Solutions

There was a linear relation between actual and observed values for calcium solutions from 0 00 to 25 0 mg% and for magnesium solutions from 0 00 to 5 00 mg% as shown in Tables I and II While the range could be extended with appropriate changes in reagent concentration in practice it was easier to dilute sample solutions so that they fell within the range used for determination of calcium and magnesium in serum

3 Precision

a *Serum Calcium and Magnesium*

18 replicate titrations of calcium and calcium plus magnesium were performed on a single serum sample The coefficient of variation of the calcium values was 87 % The coefficient of variation of calcium plus magnesium values was 83 % The S E M of the Ca titration was 20 % of the mean value and the S E M of the calcium plus magnesium was

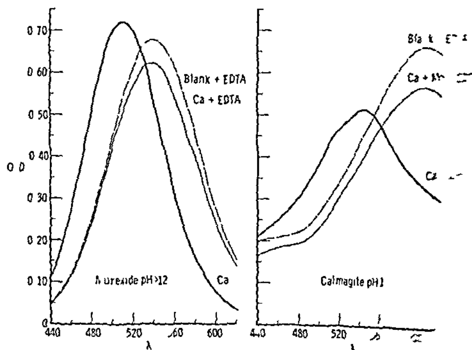


FIGURE 4 Spectra of murexide and calmagite

TABLE I Solution of Calcium Standard 5 00 to 2ɔ 0 mg %

Ca std mg	ɔ 00	10 0	1 0		
	5 00	10 00	15 1	[illegible]	[illegible]
	4 90	10 00	14 9	[illegible]	[illegible]
	5 0ɔ	10 10	15 0	[illegible]	[illegible]
	5 00	9 90	1ɔ 0	[illegible]	[illegible]
Mean value mg % ± SD	4 99 ± 06	10 00 ± 08	1ɔ 00 ± 08	[illegible]	[illegible]

TABLE II Solutions of Magnesium Standard 1 00 to ɔ 00 mg %

Mg std mg	1 00	2 00	3 00		
	1 00	1 96	30,	[illegible]	[illegible]
	1 0?	1 99	2 9ɔ	[illegible]	[illegible]
	97	2 0ɔ	30?	[illegible]	[illegible]
	1 00	1 93	2 98	[illegible]	[illegible]
Mean value mg % ± SD	1 00 ± 02	2 00 ± 04	ɔ 00 ± [illegible]	[illegible]	[illegible]

TABLE III Recovery of Calcium in Serum

Sample	Ca added mg	Calculated total Ca mg	Observed total Ca mg	Observed Value / Calculated Value
Serum "A"	5 00	15 00	15 10	100 5
10 00	5 00	15 00	14 98	99 8
(average of 4)	5 00	15 00	15 00	100
	5 00	15 0	14 95	99 7
	10 0	20 0	20 10	100 5
	10 0	20 0	20 00	100
	10 0	20 0	19 95	99 7
	10 0	20 0	19 92	99 6

Recovery is 100 00 ± .35 %

TABLE IV Recovery of Calcium in Urine

Sample	Ca added mg	Calculated total Ca mg	Observed total Ca mg	Observed Value / Calculated Value
Urine "A	5 00	16 45	16 40	99 5
11 45 mg %	5 00	16 45	16 55	100 5
(average of 4)	5 00	16 45	16 35	99.3
	5 00	16 45	16 45	100
	10 0	21 45	21 35	99 5
	10 0	21 45	21 50	100 2
	10 0	21 45	21 45	100
	10 0	21 45	21 50	100 2

Recovery is 99 90 ± 19 %

19 % of the mean value The S E M of the magnesium value which is the difference between these titrations was 27 % of the mean magnesium value

(b *Urine Calcium*

50 ml of a urine sample containing 14 2 mg% calcium was mixed with 50 ml of distilled water 16 replicate titrations of calcium yielded a coefficient of variation of 1 3 % of the mean value of 7 10 mg% The S E M was 3 % of the mean value

50 ml of the same urine sample was mixed with 50 ml of a solution of NaH_2PO containing 400 mg% P 16 replicate titrations of calcium on this sample (containing 7 10 mg% calcium and over 200 mg% P as

TABLE V Recovery of Calcium in Bone Ash

Sample bone ash 60 mg in HCl	Ca added mg	Calculated total Ca mg	Observed total Ca mg	Observed Value / Calculated Value
Bone ash	10 0	30 ..5	30 60	100 3
60 mg % in HCl	10 0	30 ..	30 .0	100
Ca content	10 0	30 ..	30 6	100 3
20 50 mg %	10 0	30 ..	30 ..	100

Recovery is 100 1 ± 17 %

TABLE VI Recovery of Calcium in Feces Ash

Feces ash Solution 100 mg in HCl	Ca added mg	Calculated total Ca mg	Observed total Ca mg	Observed Value / Calculated Value
Total calcium	10 0	23 1	23 0	99 5
13 10 mg %	10 0	23 1	23 2	100 4
(average of 4)	10 0	23 1	23 15	100 3
	10 0	23 1	23 0	99 5

Recovery is 99 93 ± 49 %

NaH PO) yielded a coefficient of variation of 1 4 % of the mean value of 7 10 mg% The S E M was 35 % of the mean values

4 Recovery of Calcium

Recovery was expressed as percentage of observed over calculated total calcium

The recovery of 5 and 10 mg% calcium added to a 10 mg% serum ranged from 99 6 to 100 5 % with a mean value of 100 00 ± 35 % (Table III)

The recovery of calcium added to urine ranged from 99 3 to 100 5 % with a mean of 99 9 ± 19 % (Table IV)

The recovery of calcium in bone ash solution ranged from 100 to 100 3 % with a mean value of 100 1 ± 17 % (Table V)

The recovery of calcium in a feces ash solution ranged from 99 5 to 100 4 % with a mean value of 99 93 ± 49 % (Table VI)

5 Recovery of Magnesium

Recovery was expressed as a percentage of observed over calculated to tal magnesium

TABLE VII Recovery of Magnesium in Serum

Sample	Mg added mg	Calculated total Mg mg	Observed total Mg mg	Observed Value / Calculated Value
Serum A	1 00	2 94	2 96	100 5
1 94 mg %	1 00	2 94	2 92	99 7
(average of 4)	1 00	2 94	2 88	98 0
	1 00	2 94	2 95	100
	2 00	3 94	3 88	98 5
	2 00	3 94	3 85	98 0
	2 00	3 94	3 98	101
	2 00	3 94	3 95	100

Recovery is 99 5 ± 1 3

TABLE VIII Recovery of Magnesium in Urine

Sample	Mg added mg	Calculated total Mg mg	Observed total Mg mg	Observed Value / Calculated Value
Urine "A"	1 00	4 46	4 46	100
3 46 mg %	1 00	4 46	4 46	100
(average of 4)	1 00	4 46	4.52	101
	1 00	4 46	4.39	98.3
	2 00	5 46	5 51	101
	2 00	5 46	5 38	98.3
	2 00	5 46	5 46	100
	2 00	5 46	5.51	101

Recovery is 99 95 ± 1 1 %

The recovery of magnesium in serum ranged from 98 0 to 100 1 % with a mean value of 99 5 ± 1 3 % (Table VII)

The recovery of magnesium in urine ranged from 99 3 to 101 % with a mean value of 99 9 ± 1 1 % (Table VIII)

The recovery of magnesium in bone ash was at least 100 % The normal magnesium content of bone ash is only about 1 to 2 % of the calcium content so that it is difficult to quantitate by difference between calcium and calcium plus magnesium titrations However there was no interference in recovering the added magnesium (Table IX)

The recovery of magnesium in a feces ash solution ranged from 99 2 to 100 8 % with a mean value of 100 ± 66 % (Table X)

TABLE IX Recovery of Magnesium in Bone Ash

Sample bone ash 60 mg in HCl	Added Mg mg	Calculated total mg	Observed total mg
		(2 to 2.2 mg %)	
Mg content	2 0	2 2	2 1
0.2 mg %	2 0	2 2	2 1
(i.e. 1 % of	2 0	2 2	2 1
Ca content)	2 0	2 2	2 1

TABLE X Recovery of Magnesium in Feces Ash

Feces ash 100 mg in HCl	Added Mg mg	Calculated total Mg mg	Observed total Mg mg	Observed Value / Total Value
Total Mg	2 00	6 10	6 10	100
is 4 10 mg %	2 00	6 1	6 10	100
(average of 4)	2 00	6 1	6 15	100.8
	2 00	6 1	6 05	99.2

Recovery is 100 ± 66 %

TABLE XI Effect of Phosphate on Titration of Calcium — Magnesium Solution in Presence and Absence of Citrate

Sample Ca 10 mg — Mg 2 mg	No added citrate Observed Ca values (mg)		With Citrate Added Observed Ca values (mg)				Mean Value — SD
No P	10 0	10 0	10 08	10 0	10 0	9 95	10 01—05
—50 mg % P	7.25	7 15	10 0	9.85	10 0	10 05	9 95—07
—100 mg % P	7.50	6.55	9 85	9 95	10 03	10 05	9 9 —08
—150 mg % P	5 90	6 60	10 0	10 0	10 10	10 03	10 05—05
—200 mg % P	5 60	6 00	10 15	9 75	10 15	10 00	10 01—18

B Effect of Citrate upon Phosphate Interference

Table XI demonstrates the decrease of observed calcium with increasing amounts of added phosphorus in a standard calcium plus magnesium solution titrated at pH 13 for calcium The protective effect of citrate upon the same solution is also shown with full recovery of calcium in the presence of 200 mg% phosphorus as Na HPO

In Table XII titration of calcium in urine in the presence of added phosphorus showed the same incomplete recovery which in the pres

TABLE VII Recovery of Magnesium in Serum

Sample	Mg added mg	Calculated total Mg mg	Observed total Mg mg	Observed Value / Calculated Value
Serum A	1 00	2 94	2 96	100.5
1 94 mg %	1 00	2 94	2 92	99 7
(average of 4)	1 00	2 94	2 88	98 0
	1 00	2 94	2 95	100
	2 00	3 94	3 88	98 5
	2 00	3 94	3.85	98 0
	2 00	3 94	3 98	101
	2 00	3 94	3 95	100

Recovery is 99 5 ± 1 3

TABLE VIII Recovery of Magnesium in Urine

Sample	Mg added mg	Calculated total Mg mg	Observed total Mg mg	Observed Value / Calculated Value
Urine A"	1 00	4 46	4 46	100
3 46 mg %	1 00	4 46	4 46	100
(average of 4)	1 00	4 46	4 52	101
	1 00	4 46	4 39	98 3
	2 00	5 46	5 51	101
	2 00	5 46	5 38	98 3
	2 00	5 46	5 46	100
	2 00	5 46	5.51	101

Recovery is 99 95 ± 1 1 %

The recovery of magnesium in serum ranged from 98 0 to 100 1 % with a mean value of 99 5 ± 1 3 % (Table VII)

The recovery of magnesium in urine ranged from 99 3 to 101 % with a mean value of 99 9 ± 1 1 % (Table VIII)

The recovery of magnesium in bone ash was at least 100 % The normal magnesium content of bone ash is only about 1 to 2 % of the calcium content so that it is difficult to quantitate by difference between calcium and calcium plus magnesium titrations However there was no interference in recovering the added magnesium (Table IX)

The recovery of magnesium in a feces ash solution ranged from 99 2 to 100 8 % with a mean value of 100 ± 66 % (Table X)

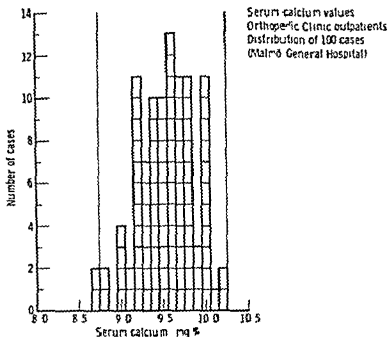


FIGURE 5

atomic absorption spectrophotometry are shown in Table XIII Although urine B was said to contain 1 8 mg% Ca it apparently contained 0 7 mg% calcium so firmly bound that it was not exchangeable with Ca in vitro even after incubation for 48 hours (Neill 1964) If then this sample actually contained only 1 1 mg% calcium the present method had a consistent overestimate of 2 % suggesting a difference in standard solutions but a high degree of internal consistency particularly in the presence of added NaCl and $MgSO_4 \cdot 7H_2O$ in samples D and E respectively (Ca Panel Report 1964)

D Serum Calcium—Normal Values

All values are averges of duplicates agreeing within 1 5 per cent

To establish the normal distribution of serum calcium values in an Orthopaedic Department blood was drawn from 100 non fasting patients presenting at the Orthopaedic Outpatient Clinic of the Malmö General Hospital who did not have evidence of bone disease or bone injury

The 53 male patients had serum calcium of 9 54 ± 34 mg% and the serum calcium of the 47 female patients was 9 52 ± 35 mg% There was *no relation between calcium concentration and age or sex* The distribution of the calcium value is shown in Figure 5 Only 2 of the 100 cases fell outside of the range 8 80 to 10 20 mg%

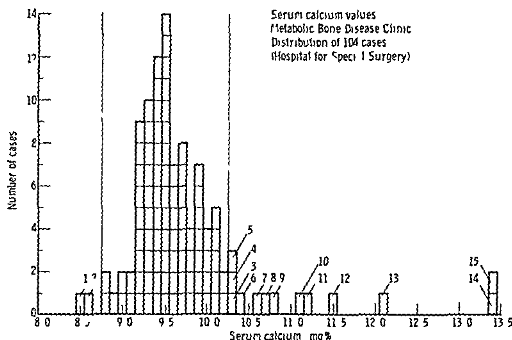


FIGURE 6

In 104 patients of both sexes drawn from the Metabolic Bone Disease Clinic at the Hospital for Special Surgery the serum calcium was 9 77 ± 84 mg% The distribution of the calcium values in this series is shown in Figure 6

Taking the normal range of serum calcium as 8 80 to 10 20 mg% (approximating ± 2 S D from the mean) the values from the Metabolic Bone Disease Clinic were recalculated on the 89 values falling within this range this resulted in a mean of 9 53 ± 33 mg% The 15 cases which fell above or below this narrow range of normal are shown in Table XIV While it is apparent that within the range 8 8 to 10 2 there are cases with metabolic bone disease in the form of Paget s disease multiple myeloma and other conditions the 15 cases with values outside these limits all have an explanation for their hypercalcemic or hypocalcemic state The two proven cases of parathyroid adenoma were detected entirely on the basis of the serum calcium done routinely in the Metabolic Bone Clinic

A further study to assess the range of plasma calcium in man was performed on blood from 227 healthy male blood donors at the Malmö General Hospital In these the plasma calcium was 9 25 ± 35 mg% The standard deviation remained the same as in the non fasting group of OPD patients The lower mean value may have been related to the

TABLE XIV Serum Calcium Values—Metabolic Bone Disease Clinic—Hospital for Special Surgery

Patient	Sex	Age	Serum Calcium (mg)	Diagnosis
1 C. H	M	68	8 45	Gastrectomy cancer of the prostate large doses of estrogens
2 M A	F	80	8 60	Osteoporosis poor calcium absorption by Ca study
3 I R	F	63	10 30	Post menopausal osteoporosis
4 H M	F	61	10.30	Paget s disease tuberculosis of the hip
5 M W	F	58	10 30	Osteoporosis healing fractures alcoholism
6 R M	F	32	10 40	Idiopathic osteoporosis myasthenia gravis high calcium diet for 3 years
7 P M	F	15	10 6	Vitamin D resistant rickets on 5 000 units daily for one year
8 V F	F	49	10 65	Hypercalcuria low phosphorus probable parathyroid disease
9 J S	F	49	10 80	Paget s disease
10 J F	M	65	11 10	Gastrectomy suspected parathyroid disease
11 A D	F	64	11 18	Proven parathyroid adenoma
12 R R	F	12	11 50	Osteogenesis imperfecta acutely decalcifying spine with fractures
13 I F	F	68	12 1	Proven parathyroid adenoma
14 M W	F	74	13 35	Multiple myeloma
15 P B	M	17	13 40	Osteogenic sarcoma with metastases

fasting state of the blood donors Another factor may have been slight hemodilution as the blood was from the end of the donation period

In a study of 102 sera taken for routine latex fixation tests at the Hospital for Special Surgery the mean serum calcium was 9 44 ± 39 mg%

E Serum Magnesium—Normal Value

All values given are averages of duplicates In the same 100 outpatients at the Malmö General Hospital—free of any evidence of bone disease the serum magnesium of 53 males was 2 24 ± 25 mg% and of 47 females 2 23 ± 21 mg%

In the same group of 227 fasting male blood donors plasma magnesium was 2 17 ± 21 mg%

IV DISCUSSION

A Direct Titration of Calcium and Magnesium

The advantages of the method described for determination of calcium and magnesium in biological samples are specificity, precision simplicity and freedom from the operator s influence

Precision in the measurement of aliquots is assured by the automatic pipet calibrated to contain which is washed by the diluting solution for complete delivery independent of differences in viscosity between samples and standards

The simple dropwise addition of reagents to the titrating solution is not a critical step since doubling any of these has no measurable effect upon the end point Impurities leading to colour changes can only affect the absorbance axis of the record and not the titration end point Similarly the colour of the serum or urine aliquot itself has no effect on the titration end point

The interferences recognized in other methods do not affect this procedure as described Excesses of Na or K which affect flame methods have *no influence on the EDTA titration Magnesium does not react at* the pH at which calcium is measured yet is titrated quantitatively at the lower pH of the calcium plus magnesium titration

Phosphate interference which in other methods necessitates prior sample treatment is eliminated by the simple addition of citrate in excess No prior treatment aside from acidification is required for the determination of calcium or calcium plus magnesium in urine

Freedom from interference permits precise measurements of calcium and calcium plus magnesium directly on aliquots of any biological material in solution with total calcium content of the aliquot as low as 10—20 μGm

The incineration procedure removes much of the difficulty of assaying stool and tissue calcium content

B *Serum Calcium and Magnesium in Man*

Advances in the precision of analytical methods have led to a new concept *of the normal range of serum calcium and magnesium in man*

The results reported here for serum calcium are in agreement with those reported by Copp (1963) who found the mean value for 54 normal adults to be 9 40 ± 32 mg% Ca and Jones and McGuckin (1964) who found serum calcium in 40 normal adults to be 9 47 ± 29 The range of normal is remarkably low attesting to the precision of the homeostatic mechanisms controlling the concentration of this electrolyte in body fluids

If 95 % of all serum calcium values in a normal population fall within the range 8 80 to 10 20 mg% (mean ± 2 SD) it is apparent that values outside this narrow range take on a new meaning when compared to the previously accepted much wider range of serum calcium. The 15 cases from the Metabolic Bone Clinic series which were outside this normal range supported this view. See Table XIV

Continued reliance in the clinical laboratory upon serum calcium methods with a precision of ± 5 % can not be justified when the range of normal is so narrow

Serum magnesium also falls within a narrow range. The values reported here agreed well with the 2 23 ± 27 mg% serum Mg reported in 18 cases by Malmstadt (1959) using an EDTA titration method

C Determination of Abundance Levels of Calcium Isotopes

Estimation of the relative abundance levels of the calcium isotopes has depended until recently upon mass spectrometric analysis. With the development of neutron sources and improved measurement techniques activation analysis has been used to study the abundance of calcium isotopes in the natural environment (Corless 1964). The precision of the estimation of abundance of calcium isotopes with this technique is dependent upon the precision of total calcium estimation by EDTA titration

The production of enriched Ca and Ca has made possible this use as stable tracers of calcium kinetics (McPherson 1964). The amount of Ca or Ca in a calcium sample is determined by activation analysis counting the Ca or Ca produced in samples and standards. The abundance level of stable isotopes can then be determined if the total calcium of the activated sample and standard can be determined accurately. The EDTA titration described here has been used for the determination of total calcium in such activated samples. Abundance levels of Ca and Ca in samples expressed as per cent dose per gram of total calcium permit construction of specific activity curves for stable isotopes used as tracers

V CONCLUSIONS

A direct recorded EDTA titration procedure permits precise measurement of total calcium and total calcium plus magnesium giving magnesium by difference in a variety of biological materials

Phosphate interference during titration is prevented by the addition of citrate in excess

The normal range of serum calcium and serum magnesium is very narrow (9 50± 35 mg% and 2 24± 21 mg% respectively) Deviations from this narrow range observed in a sample of patients from a Metabolic Bone Clinic have been important in the diagnosis of a variety of conditions

Precision in estimation of total calcium in small samples has permitted the use of this method in the determination of the abundance of stable calcium isotopes used as tracers of mineral metabolism using neutron activation analysis

Heavy Calcium Isotopes as Tracers of Calcium

I INTRODUCTION

A Reported Ca* Specific Activity Differences

Unexplained differences in specific activity of heavy calcium isotopes between blood and urine have been reported by several investigators in man and in experimental animals The apparent differences observed have been attributed in some cases to binding of these isotopes by blood proteins as evidence of a calcium pool within plasma (Wiester *et al* 1963 Veall and Parsons 1964) Others have reported variation in S A ratios of blood and urine but have been unable to state whether these were real or due to systematic analytic errors (Dow and Stanbury 1960) Profound variations in blood/urine Ca* specific activity ratios have been related to starvation in both rats (Likins and Craven 1960) and sheep (Giese and Comar 1964)

B Isotope Effects

Isotopes of an element do possess different chemical characteristics and some degree of fractionation has been shown to occur in both geological and biological processes These isotope mass effects range all the way from the profound disturbances produced in biological systems by Deuterium (Kritchevsky 1960) to the slight variation in O C and S isotope abundance ratios which are important in geological studies (McDowell 1964)

While Deuterium and Tritium are particular examples of the importance of isotope mass effects the mass differences between Ca and its heavy isotopes radioactive Ca and Ca and stable Ca and Ca are relatively greater than those that occur in other elements commonly used as tracers in biological systems and because of this one might expect some fractionation to occur Differences in abundance of isotopes in the natural environment have usually been observed when the element has been taken through complex systems such as carbon in photosynthesis sulfur in bacterial decay processes in petroleum deposits and carbon in precipitation of calcite (McDowell 1964) Corless has sug

gested that $^{44}/^{40}$ calcium isotopic abundance variations may occur in cal cified tissues (IAEA 1964)

Processes which do discriminate tend to conserve isotopes of lower mass so that if fractionation of calcium isotopes did occur one would expect that heavier Ca and Ca would be discriminated against by ac tive transport mechanisms such as occur in the renal tubules Reabsorp tion processes absorb relatively more easily the isotope requiring the least energy i e ^{40}Ca Differences on this basis due to biological frac tionation would thus tend to result in higher Ca* S A in the urine than in the serum

That some biological fractionation of calcium isotopes may exist is not seriously questioned However such differences are probably far less than those of biological variation inherent in experiments under taken in the complex milieu of the intact animal Such factors as renal blood flow delay of urine in transit related to its flow rate etc will of course affect short term studies but will be less significant in experi ments over several hours days or weeks as is the usual case in calcium tracer studies

The purpose of the investigation reported here was to evaluate re ported Ca* S A differences between serum and urine in human subjects Special attention was given to the possibility that heavy Ca isotopes are fractionated as compared to lighter Ca isotopes

II MATERIALS AND METHODS

A Specific Activity Studies with ^{47}Ca

1 Subjects

Case 1 R M A 77 year old male with diabetes and a vertebral com pression fracture secondary to post gastrectomy osteoporosis The pa tient was confined to bed during most of the study period

Case 2 W J A 40 year old male with back pain secondary to rheu matoid spondylitis and associated severe osteoporosis The patient was ambulatory during the study

Case 3 E G A 48 year old female with severe back pain related to osteoporosis and compression fractures of vertebrae secondary to cor ticosteroid therapy of dermatomyositis The patient was confined to bed and wheel chair during study

All cases received a normal hospital diet

2 Procedure

After voiding each subject received 50—75 μc Ca intravenously as $CaCl_2$ solution containing a negligible amount of carrier calcium

Blood was drawn from the antecubital veins Serum was separated and stored in the cold

Patients voided at their usual times using a clean acid washed glass bottle for each voiding The time period of each collection was recorded

Collections continued over a 7 to 9 day period

3 Ca Specific Activity Determination

a 'Ca Assay

3 0 ml aliquots of serum and of each urine sample were placed in glass sample tubes and counted in an automatic well counter (Nuclear Chicago) against a 'Ca standard solution representing 17 % of the dose administered

Counting accuracy was kept to at least 2 per cent

b *Total Calcium Assay*

Total calcium concentration in the serum and in urine samples was measured using direct EDTA titration

Specific activity was expressed as % dose Ca per gram total calcium

B 'Calcium Abundance Studies

Calcium isolated as calcium carbonate from samples of human and rat bone and human urine was analyzed for its Ca abundance in relation to standard CaCO samples by neutron activation analysis Ca produced from the Ca by n / reaction under neutron bombardment was counted in relation to standard samples Total calcium estimation on the activated standard and samples gave abundance ratios of Ca in the samples in relation to the reference standard employed

III RESULTS

A Radioactive Studies Using Ca

Figures 7 8 and 9 show the change with time of serum and urine calcium in the three cases studied with Ca

The urine specific activity is plotted at the mid points of collection periods While this does tend to a slight over estimation this is not significant after the initial rapid drop of Ca S A in the first day

It is apparent that urine and serum Ca specific activity fall on the same curve in the three cases

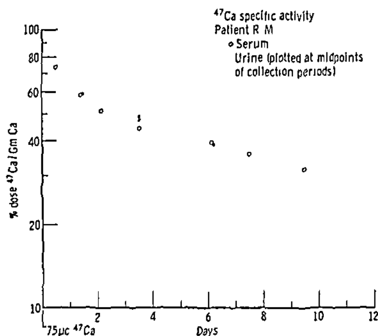


FIGURE 7

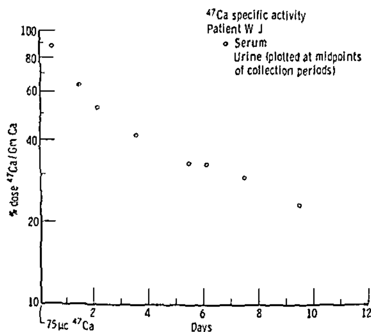


FIGURE 8

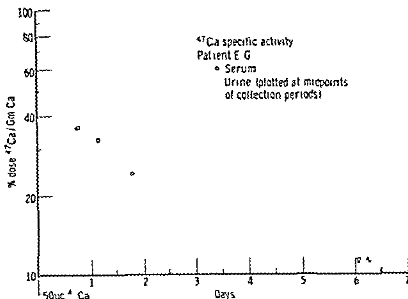


FIGURE 9

TABLE XV

Calcium Source	Total Calcium Activated (m)	⁴⁴Ca Abundance	⁴⁴Ca Abundance Sample / ⁴⁴Ca Abundance Standard × 100
CaCo	6 a0	182 *	100
$CaCO_3$	5 a8	182	100
Human Urine A (7 precipitations)	7.51	182	100
Human Urine A (3 precipitations)	7 91	173	95
Rat Bone Ash R	8 02	174	95 6
Rat Bone Ash R	5 92	178	97.8
Human Bone Ash H	8 21	181	99 4
Human Bone Ash H	7 14	181	99 4

* Primary Calcium Standard Mallinckrodt 4071

B Ca Abundance Studies

Ca abundance values in samples of rat and human bone and urine from several patients as a ratio of standard calcium samples are shown in Table XV The isotopic ratios in the samples are similar The control and post study Ca abundance levels in a series of patients injected with Ca as tracer showed abundance levels similar to standard calcium samples (Table XV)

IV DISCUSSION

A Previous Studies

Considerable evidence is available to support the contention that serum Ca*S A is reflected by the urine Ca*S A in experiments where reasonable time has been allowed to elapse for equilibration in body pools before sampling

Govaerts (1949) studied the excretion of "Ca infused in dogs and reported the same S A in serum and urine In 1945 Blau *et al* gave 'Ca orally to two patients and found the S A curves of plasma and urine to be the same over a 9 day period of study After the second hour following ' Ca given orally urine S A was representative of serum S A They confirmed these observations in other human cases in which the tracer was given intravenously

Bronner *et al* (1956) injected ' Ca intravenously in 9 adolescent mentally defective boys and found that serum and urine S A fell in the same curve In one young adult this was true over a longer period of 30 days

Krane *et al* (1956) also followed the serum and urine S A of 15 cases of thyroid disease given Ca intravenously and found S A to be the same

Heaney and Whedon (1958) also showed similar urine and serum S A *in 4 representative cases of 12 studies with intravenous 'Ca for* periods up to 10 days

The subject of Ca S A was considered at the Second Panel on Medical* Uses of ' Ca (Vienna 1964) Corey *et al* (1964) stated that fractionated urine can t be obtained early in the study and the S A of urine calcium is often different from that in serum however they had no difficulty in the use of Ca* S A in saliva as representative of S A in blood There seems little reason to expect basic differences in S A to be produced by the filtration and reabsorption processes in renal tissue that are not produced by the secretion processes of the salivary glands

At the same Panel on ' Ca Soto *et al* (1964) reported that in a variety of disease states as well as in normals the ' Ca S A of serum and urine did not differ significantly after the first day of 7 to 8 day studies In their series were included 10 normals 11 hyperthyroids 9 hypothyroids 6 cured cases of thyrotoxicosis 4 hypoparathyroids and 5 cases of osteoporosis If differences were to appear then this series should certainly have presented opportunity with its variety of metabolic disorders Soto *et al* (1964) reported the same findings in 8 cases given ' Ca orally

Szymendera (1964) presented data on three patients given ' Ca intravenously showing *excellent agreement of S A in plasma and urine and*

employing EDTA titration to assay total calcium in the samples The ease of sample preparation in ⁷Ca studies compared to the relative complication of precipitation procedures needed to prepare ⁴ Ca for isotope assay suggests that Ca S A measurements on serum and urine are more likely to be true values

Animal experiments on normal dogs by Miller *et al* [1964 (a)] and by Giese and Comar (1964) on normal sheep showed the same S.A of serum and urine ⁴⁵Ca

Investigations noting a difference in Ca* S A between blood and urine have been reported by a number of authors In the light of evidence provided by the studies discussed above as well as the Ca* S A relationship observed in the three cases studied with Ca described here these reports have been examined

The controversy appears to date from a report by Dow and Stanbury (1960) describing serum to urine ⁴Ca S A ratios of from 1 18 to 3 86 in human subjects

The significance of this finding in relation to the 15 cases described in 1956 by Krane *et al* in which Stanbury took part is not explained Dow and Stanbury (1960) were unable to state whether their observations were real or were related to analytical errors in the precipitation procedure used for both serum and urine calcium Veall (1962) in studying such procedures checked with ⁴Ca has found from 62 to 75 % recovery of total calcium from urine with oxalate precipitation methods The co precipitation of magnesium in urine under certain conditions can give a false high estimate of urine total calcium and account for a low S A in urine relative to plasma (Fiske and Logan 1931)

Following Dow and Stanbury s (1960) report other authors have commented upon the possibility of multiple calcium pools in blood which do not exchange as rapidly as expected and could thus account for S A differences

Veall and Parsons (1964) proposed that the complexed diffusible forms of calcium in plasma i e calcium bound to organic acids sulfate and phosphate were not available for rapid exchange with calcium tracers These forms of calcium were supposed to be preferentially excreted since the ionic form is more available for tubular reabsorption Although Veall stated that this complexed pool of calcium should be considered in models of calcium kinetics he did not present evidence to support this view

Further support for this hypothesis came from Wiester *et al* (1963) based upon 4 blood samples drawn from a parathyroidectomized dog given an infusion of Ca and ⁴ Ca over a period of three hours Their observation that urine S A was only 55—70 % that of plasma ultrafil

trate depended upon oxalate precipitation of calcium—with possible errors in over estimation of total calcium in urine due to magnesium interference

Giese and Comar (1964) reported similar Ca* S A in the serum and urine of 2 normal sheep but found lower urine Ca* S A in the same 2 animals when starved 48 hours despite the fact that total plasma calcium changed only slightly. The lower S A was associated with increased 'Ca in the urine in one sheep and increased ⁴⁰Ca in the other when compared with the values in the fed control experiment. An in vitro equilibration of Ca with plasma of normal and starved sheep showed no difference. This did not support the idea that complexed non exchangeable pools of calcium in plasma were responsible for the Ca* S A difference in the starved sheep

Similar apparent differences in ' Ca S A in starved rats were noted by Likins and Craven (1960). In both the rats studied by Likins and Craven (1960) and the sheep studied by Giese and Comar (1964) the total calcium of urine was determined by oxalate precipitation. Since magnesium may interfere in these methods and since starved animals may excrete many times as much magnesium as calcium in urine (Fiske and Logan 1931) these two factors may explain these results in starved animals

Studies of the S A of blood and urine of dogs by Miller (1964) and Miller and Neuman (1964) leave little doubt that in the normal state Ca* S A is the same in blood and urine. They employed EDTA titration *of the counted samples and so avoided the possibility of magnesium interference. The differences observed in their experimental preparations are related to marked disturbances in renal function performed to study calcium exchange in kidney tissue*

Table XVI *summarizes the evidence which has been presented concerning the serum urine Ca* S A ratio The 3 cases reported here studied with Ca showed that urine Ca* S A was representative of serum Ca* S A and are in agreement with the findings reported by Soto *et al* 1964 Szymendera 1961 Heaney and Whedon 1958 Krane *et al* 1956 Blau *et al* 1954 and Bronner 1956 in a total of 86 human subjects including normal cases and cases suffering from various metabolic bone diseases. Dow and Stanbury s (1960) report on 10 cases is the only one in which S A differences were observed in man. They were unable to rule out systematic error in the urine calcium method employed (Stanbury 1964)

In normal animals the Ca* S A of urine and serum was the same in rats (Likins and Craven 1960) dogs (Govaerts 1949 Miller 1964 Miller *et al* 1964) and sheep (Giese and Comar 1964) Ca* S A differences

TABLE XVI Serum — Urine Calcium* Specific Activity

Author	Cases	Subjects	Isotope	Urine Calcium method	Relation of serum to urine S A
Blau et al 1954	2	man	Ca	precipitation	same
Krane et al 1956	15	man	Ca	precipitation	same
Bronner et al 1956	9	man	⁴⁵Ca	precipitation	same
Heaney and Whedon 1958	12	man	⁴Ca	precipitation	same
Dow and Stanbury 1960	10	man	Ca	precipitation	urine S A lower than serum in all cases
Szymendera 1964	3	man	'Ca	EDTA titration	same
Soto et al 1964	45	man	'Ca	EDTA titration	same
Govaerts 1949		dogs	Ca	precipitation	same
Likins and Craven 1960	6	rats	⁴⁵Ca	precipitation	same in normals
Likins and Craven 1960	8	rats	Ca	precipitation	urine S A lower in starved animals
Wiester et al 1963	1	dog	'Ca	precipitation	urine S A lower
Giese and Comar 1964	2	sheep	Ca	precipitation	same in normals urine S A lower in starved animals
Miller et al 1964		dogs	Ca	EDTA titration	same

found in animals have been in 4 blood samples from 1 parathyroidec- tomized dog (Wiester *et al* 1963) starved rats (Likins and Craven 1960) and starved sheep (Giese and Comar 1964) as well as in the spe- cialized stop flow studies of renal calcium exchange reported by Miller *et al* 1964 Magnesium interference in the methods used for urine cal- cium in the starved animals may account for the apparent lower Ca* S A in these studies

B Present Study

The close agreement of urine and serum ⁴Ca S A in the three cases re- ported here did not support the existence of significant isotopic frac- tionation processes due to either complexed calcium pools in plasma or to active transport mechanisms in the kidney

The constancy of ⁴Ca abundance ratios in a variety of biological [illegible] samples including urine and bone did not suggest that there was [illegible] nificant degree of biological fractionation which would [illegible]

against the heavy calcium isotopes otherwise there would have been differences in [illegible]Ca abundance not only between bone samples and urine samples but also between different urine samples These findings do not support the observations of Corless and Winchester (1964) who found differences of [illegible] Ca abundance ratios between human teeth and geological calcium samples They acknowledged however, that the method employed required further refinement

The use of urine Ca*SA as a measure of plasma Ca*SA is of considerable importance First it is possible to extend the time of a tracer study by concentration of urine calcium by various means, and also to decrease the dose of tracer according to the concentration factor Secondly it is possible to employ the isotope abundance pattern of urine Ca as a measure of the isotope abundance pattern of plasma calcium In studies of calcium kinetics using stable isotopes of calcium the 10 mg samples needed for activation analysis can be isolated from timed urine collections thus avoiding the need for large volumes of plasma This method has been adopted as a means of following the plasma S A of stable [illegible]Ca and [illegible]Ca used as tracers of calcium kinetics in man

V CONCLUSIONS

Studies of [illegible]Ca specific activities in serum and urin in three human subjects did not reveal evidence of fractionation of heavy calcium isotopes sufficient to invalidate kinetic studies using that tracer

[illegible]Ca abundance in a variety of samples of biological origin was constant in relation to standard calcium samples The abundance of [illegible]Ca is apparently constant in nature

Urine calcium specific activity is representative of serum calcium specific activity Studies of calcium kinetics using stable isotopes may be performed using activation analysis of 10 mg samples of calcium isolated from urine

Kinetic studies with calcium isotopes can be extended in time by concentrating urine

^{46}Ca and ^{48}Ca as Tracers in Studies of Mineral Metabolism

I INTRODUCTION

Tracer studies using radioisotopes have led to a dramatic increase in knowledge not only of the mechanisms but also of the kinetics of physiological processes. At the present time more than two dozen radioisotopes possess properties which make them of actual or potential value in the study of skeletal tissues alone (McLean and Budy, 1964).

A Stable Isotopes of Calcium

Recently the development of more efficient separation procedures in an effort to secure high specific activity radioactive tracers has led to the production of stable isotopes in highly enriched forms. Table XVII lists the stable isotopes of calcium and their enrichments available at the present time (Beauchamp, 1964).

Stable isotopes are suitable for tracer studies provided that:

1 normal abundance of the isotope is low in nature
2 highly enriched forms of the isotope are available
3 increased abundance of the isotope in sample materials can be accurately measured

This report describes the use of two stable isotopes of calcium, ^{46}Ca and ^{48}Ca as tracers in studies of calcium metabolism in man and animals.

B Abundance Measurement

1 Mass Spectrometry

The abundances of the isotopes of calcium determined by mass spectrometry are shown in Table XVIII. These values compare very favourably with those given by Nier (1938) who discovered ^{46}Ca and ^{48}Ca.

Mass spectrometry provides the most precise means of estimating the abundance of isotopic species provided that a pure sample of the element can be obtained. In the case of calcium, as little as 100 μGm of

TABLE XVII

Isotope	Percentage enrichment
^{42}Ca	25 to >85
^{43}Ca	20 to >65
^{44}Ca	75 to >98
^{46}Ca	0.5 to 40
^{48}Ca	5 to >95

Stable Calcium Isotope Enrichment Levels Available April 1964

TABLE XVIII Abundance of the Isotopes of Calcium in Nature

Mass	40	42	43	44	46	48
Mole per cent	96.92	0.64	0.132	2.13	0.0032	0.179

From White and Cameron Physical Reviews 74 991 1948

the element is sufficient for analysis of abundance by this method As the result is a complete pattern of the abundances of the isotopes in relation to each other the total weight of sample is not critical This method is readily applied to determination of the abundance of ^{42}Ca ^{43}Ca ^{44}Ca and ^{48}Ca It has been used to study the isotopic composition of the calcium of meteorites (Hirt and Epstein 1964) and is used routinely to accurately determine enrichment levels of isotopes prior to the production of radioactive isotopes by neutron bombardment

2 Neutron Activation Analysis

The demonstration that radioactive isotopes could be produced artificially led Hevesy as early as 1936 to suggest that the technique we now know as neutron activation analysis could be used to quantitate elements at tracer levels The wider application of this analytical method awaited the later development of better neutron sources with higher fluxes and more sensitive counting apparatus employing multichannel analyzers and gamma ray spectrometry

Activation analysis is a two stage process A small amount of the sample to be analyzed is exposed for a suitable period of time to a neutron flux Many of the stable isotopes in the sample will be activated—depending upon the flux the cross section for neutron capture of the isotopes present and their abundance in the sample

In the second stage the induced radionuclides are identified by their characteristic γ ray spectra and half lives. Comparison of the activity in the sample with that of a standard radiated under the same conditions permits quantitation of the induced radioisotopes and thus the amount of their stable precursors in the sample.

The relation between radioactivity induced in an isotopic species by a constant flux and the amount of the isotope present is given by the equation

$A_x = F\sigma N (1 - e^{-\lambda t})$

where N_x = no. of target atoms of type X

σ = activation cross section of type X atoms

A_x = disintegration rate of the radioisotope produced from X as result of neutron bombardment

λ = disintegration constant

t = time of bombardment

F = flux of neutrons

Disintegration rate is proportional to mass and the sensitivity is proportional to both the cross section for neutron capture and the flux employed. Theoretically this relationship permits absolute quantitation of the isotopic species present but in practice standard samples are usually used for reference. Repeated analyses of the same sample are possible as the method is non destructive.

Neutron activation analysis has been used to determine trace elements in tissue and in serum (Bethard *et al* 1963, Koch *et al* 1958 and Rieffel *et al* 1957).

For example, the exposure of 10 ml of human serum to a neutron flux of 2.5×10⁸ n/cm²/sec for one hour produces the following range of isotopes with over 30 disintegrations/min: Na, Cl, Br, Br, Br, I, K, Ca, Mg, Co, Mn (Spencer *et al* 1957). Unless a separation procedure is performed before or after the activation step and before counting, the high background activity of the other isotopes may interfere with measurement of a particular nuclide.

Because of both its high cross section for neutron capture and its generally high concentration in biological samples, sodium in the form of Na ($t_{1/2}$ 15 hrs) is responsible for most of the activity induced in serum and other biological samples. At 12 hours other isotopes with shorter half lives have decayed to the point where 99.6% of the gamma activity is due to Na (Spencer *et al* 1957).

The short lived γ emitting isotope Ca ($t_{1/2}$ 8.7 min) produced by n, γ reaction from Ca under neutron bombardment must be counted soon after activation. Although Na does not interfere with counting of the

wise with stirring until a cloudy white precipitate formed pH was adjusted to 4 0 and the sample set aside to cool for 1/2 hour

The contents of each beaker were filtered on Munktell s 007 ash free paper in Buchner funnels using suction An additional 500 ml of water was used to wash the filtered precipitate After drying, the filter paper containing precipitated calcium oxalate was ashed in a muffle furnace at 500° C for 2 hours

The calcium carbonate resulting from the first precipitation and ashing procedure was then dissolved in 2N HCl and washed into a Pyrex beaker and after dilution to 500 ml, the entire hot precipitation filtration and ashing procedure was repeated

The calcium carbonate from the second precipitate was transferred to Pasteur pipettes the ends of which were sealed with Parafilm

The small polyethylene capsules used to contain 25 mg of calcium carbonate for activation analysis were easily filled by placing the narrow end of the Pasteur pipet inside the capsule and tapping the pipet gently while the capsule rested on a balance

e *Removal of Sodium During Isolation of Calcium*

To determine the extent to which the precipitation and washing procedures removed sodium tracer [illegible]Na was added to a series of urine samples and the [illegible]Na in the first and second precipitate was measured in relation to the recovery of calcium

2 Measurement of Stable Isotopes

a *Mass Spectrometry Analysis of Abundance*

Analyses were performed upon 100 μGm samples of calcium at the OakRidge National Laboratory

b *Neutron Activation Analysis of Ca and [illegible]Ca*

An early coded series of samples in which the total calcium content was measured by weight of $CaCO_3$ in the sample activated was analysed for [illegible]Ca content in three activation analysis laboratories Sweden (Hägermark 1963) France (Laverlochere 1963) and the United States (Rupp 1963) At the three laboratories, weighed samples of 5 to 10 mg calcium as calcium carbonate in polyethylene containers were activated in a neutron flux from 10[illegible] to 6 5×10[illegible] n/cm²/sec for periods of one to 10 minutes depending on the neutron flux of the reactor concerned The Ca produced was counted for 3 to 5 minutes using gamma scintillation spectrometry

In each case the abundance of Ca in the samples was expressed as a ratio relative to a standard with normal abundance

In all later series 'Ca samples activated at the Union Carbide Research Reactor Tuxedo Park N Y the calcium content of the activated samples was determined by direct EDTA titration The Union Carbide Facility is a 5 megawatt swimming pool reactor with a flux of 3×10" n/cm /sec Activation time for 10 mg samples of calcium as carbonate was 1 or 2 minutes After a 5 minutes delay period to allow decay of very short lived nuclides the 'Ca in the samples was measured by gamma scintillation spectrometry Counting times of 1 to 5 minutes for each sample at 50 000 c/m were employed Data were collected on punch tape and computed automatically to measure Ca by its 3 1 MeV peak

Typical γ ray spectra recorded during counting periods on a sample and a standard of calcium carbonate illustrate the peaks due to other nuclides

Samples containing increased abundance levels of Ca were prepared in the same manner used for Ca Twenty five mg of CaCO was placed in a quartz container with a capacity of 1 ml Each container was then tightly wrapped in aluminium foil All the samples and standards from two human studies were placed in an aluminium cylinder 20×6 cm and sent to the Brookhaven National Laboratory Upton N Y for activation The container was placed in a flux of 1 4×10 /cm /sec for 7 days

For counting of the Ca in the activated samples a 2 ½ well crystal and a multi channel analyser were used One week following removal from the reactor the shortlived contaminating isotopes had decayed to a negligible level The 'Ca activity was now estimated by counting the 1 3 MeV photo-peak There was reason to believe that activity from other activation products interfered only slightly at this point in time Three weeks later however (more than 4 ' Ca half lives) more long lived *contaminations began to predominate the most important of these* seemed to be "Fe

For the effective use of Ca as a tracer more elaborate counting procedures will probably be required Stability of the equipment is of great importance *computer analysis of spectra* or *radiochemical separations* will be needed to confirm the observations made during the decay of these activated samples

3 Determination of Total Calcium

Calcium content of activated samples and of urine and bone ash solutions was determined using a direct recorded EDTA titration procedure

4 Calculation of Stable Isotope Dosage

Addition of an enriched stable isotope to a quantity of calcium e g the exchangeable body pool increases the abundance in that pool in pro-

portion to the mass of the isotope added The abundance increase above the normal level may then be expressed in terms of per cent dose stable isotope per gram natural calcium In the case of ^{46}Ca (abundance 0 0032 %) one gram of natural calcium contains 032 mg of ^{46}Ca Addition of as little as 32 mg of 100 % abundance ^{46}Ca would raise the abundance level in one gram of calcium ten times *above* the normal level As the isotope is diluted by exchange and removal processes acting upon this theoretical one gram pool the increase of abundance level *above normal* at any point in time is proportional to the specific activity of the isotope (% dose ^{46}Ca/Gm calcium)

^{48}Ca has a normal abundance of 179 % so that 1 gram of natural calcium contains 1 79 mg ^{48}Ca Increasing the abundance level in a 1 gram pool by ten times above normal requires a dose of 17 9 mg of 100 % enriched ^{48}Ca

The choice of isotope and enrichment used is thus governed by expected pool size natural abundance and the available enrichment of the isotope in relation to the total mass of natural calcium in the dose, an important consideration when low enrichments are used

B Kinetic Studies with ^{47}Ca and ^{48}Ca

1 Parallel Kinetic Studies with ^{47}Ca and ^{48}Ca in Man

Urine was collected from two human subjects following intravenous injection of a tracer dose of ^{47}Ca and ^{48}Ca as its 10 4 % enrichment in the form of $CaCl_2$ in sterile water The dose administered was checked by counting the ^{47}Ca activity in the syringe before and after injection Each patient received 20 μc ^{47}Ca combined with 4 0 mg of ^{48}Ca as its 10 4 % enrichment Subject H 1 was a 20 year old normal male with a knee injury and Subject H 2 was a 48 year old woman with osteoporosis There were no restrictions of diet or activity

The ^{47}Ca specific activity of the urine samples was determined by counting ^{47}Ca activity of the entire sample in a large well counter followed by determination of total calcium in the sample by an EDTA titration method

^{48}Ca abundance in the samples was determined using both mass spectrometry and neutron activation analysis of pure calcium isolated as $CaCO_3$ Total calcium of the activated samples was determined by weighing the 25 0 mg of $CaCO_3$ submitted for activation

The specific activity of both ^{47}Ca and ^{48}Ca was expressed as % dose per gram calcium

2 Parallel Kinetic Studies with ^{47}Ca and ^{45}Ca in Rats

Five female Wistar rats fed a normal diet were each injected intraperitoneally with 25 μc Ca combined with 2 0 mg Ca as its 39 7 % enrichment in the form of $CaCl_2$ in 2 ml sterile water The dose given each animal was determined by weighing the syringe used

At 7 days the animals were killed with ether and the incisors femora *and tibiae were removed The 4 incisors 4 shafts of the 4 bones* and the 8 ends of the long leg bones as well as the remainder of the rat were ashed at 500° C for 12 hours

The resulting ash was dissolved in 2 N HCl and diluted to an appropriate volume with water The total calcium and the ^{47}Ca activity of an *aliquot of each ash solution was measured to give specific activity of* ^{45}Ca in each sample as % dose Ca/Gm calcium

Calcium as calcium carbonate was isolated from each solution by double oxalate precipitation and 25 mg aliquots of $CaCO_3$ were placed in sealed polyethylene capsules for activation analysis of Ca content at the Union Carbide Reactor

Total calcium in the activated samples was measured by direct EDTA titration of the contents dissolved in HCl

3 Kinetic Studies with Ca in Man

Two human subjects were *injected intravenously with tracer doses of* Ca Subjects B N and D M were 32 year old physicians in good health who continued normal activities and consumed a normal diet during the study

Ca was given as the 7 % enrichment in solution as $CaCl_2$ B N received 2 94 mg calcium containing 206 mg Ca D M received 2 64 mg calcium containing 185 mg Ca

Calcium was isolated by oxalate precipitation from timed urine collections during the week following injection. Samples of 25 0 mg $CaCO_3$ were then activated by neutron bombardment for one week at the *Brookhaven National Laboratory and the Ca abundance was then determined* as described above

C Normal Abundance of Ca

The abundance of Ca in samples of human bone rat bone human urine and a Primary Calcium Standard (Mallinckrodt 4071) was determined by neutron activation analysis of calcium isolated as $CaCO_3$ The total calcium of the activated samples was determined by direct EDTA titration to study the range of Ca abundance in such diverse samples

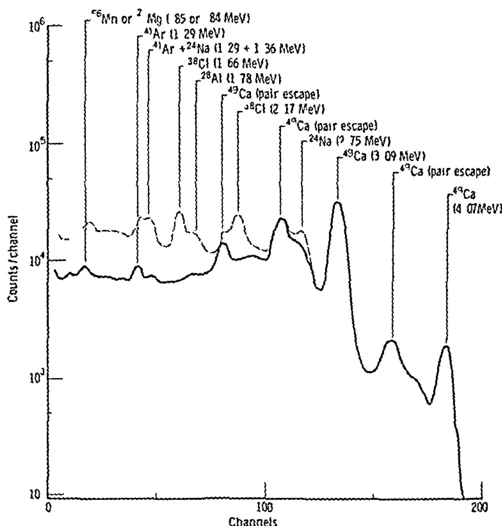


FIGURE 10 Gamma ray spectrum of 10 mg sample of calcium isolated from human urine (normal abundance) shown by thin line compared to spectrum of 10 mg of standard calcium (Primary Standard Calcium Carbonate Mallinckrodt 4071) shown by the dark line

III RESULTS

A Determination of Abundance Levels of "Ca and "Ca

1 Isolation of Calcium from Biological Samples

The double oxalate precipitation and ashing procedure isolated calcium from urine and bone samples as calcium carbonate of sufficient purity that no significant interferences from other elements were encountered in mass spectrometric analysis or neutron activation analysis in any of the four laboratories concerned Comparison of the gamma ray spectra

TABLE XX Removal of Sodium during Oxalate Precipitation of Calcium from Urine

Per cent Sodium Remaining in Sample					Per cent Total Calcium Remaining in Sample			
Sample	A	B	C	D	A	B	C	D
First Precipitation	0.9	0.84	1.84	1.32	87	94	85	95
Second Precipitation	0.004	0.003	0.004	0.005	81	84	81	85

of a standard and a sample of calcium isolated from urine demonstrates the relative purity of the samples (Fig 10)

Table XX shows calcium and Na recovery during a typical double precipitation The hot precipitation and washing was very effective in removing sodium which is the most important source of interference (as Na) in the activation analysis of biological samples

Although Na did not interfere with the counting of Ca due to the differences in their gamma ray energies the removal of sodium before activation markedly lessened the over all activity of the samples and simplified the postradiation counting and handling procedures

2 Abundance Measurement of Ca by Mass Spectrometry and Neutron Activation Analysis

The abundance of Ca in calcium samples from two patients injected with Ca and Ca was determined by neutron activation analysis in three laboratories Mass spectrometry was also used to estimate abundance in some of the samples (Table XXI) The values are expressed as a ratio (per cent) of the Ca abundance of enriched samples to the Ca abundance of calcium isolated from pre injection urine samples

The discrepancies noted in these results could have been due to the fact that total calcium values were derived from the weight of $CaCO_3$ in the activated samples Differences in the true value of calcium mass by this means related to temperature variations during ashing could thus affect the true value for Ca abundance

In all later studies performed total calcium was determined directly by EDTA titration of activated samples to improve the precision of total calcium and thus the estimation of abundance levels of both Ca and Ca

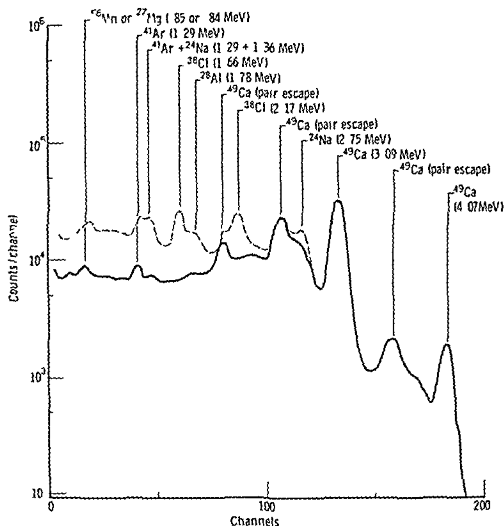


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III RESULTS

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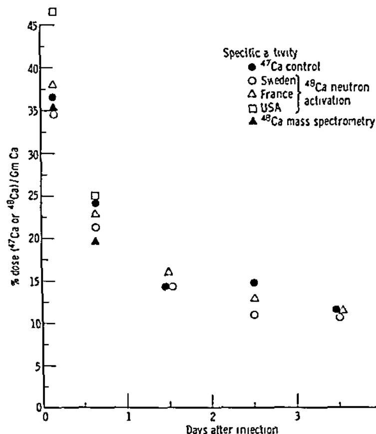


FIGURE 12

B Kinetic Studies with Ca and Ca

1 Parallel Kinetic Studies with ^{47}Ca and 'Ca in Man

The results of parallel kinetic studies using Ca and 'Ca in 2 human subjects are shown in Figures 11 and 12 The agreement between spe cific activity values derived from the two isotopes was satisfactory Errors related to weighing the 25 0 mg samples of CaCO which were activated in these 2 cases could account for some of the discrepancies noted but the validity of the use of stable calcium isotopes as tracers is apparent

2 Parallel Kinetic Studies with Ca and Ca in Rats

The relation between specific activity of ' Ca and Ca in the samples of calcium isolated from the teeth shafts and ends of long bones as well

TABLE XXII Relation between 'Ca and ' Ca Specific Activity in Calcium isolated from Rat Bones and Teeth and Whole Body

Whole Body	^{47}Ca Specific Activity	^{45}Ca Specific Activity
No 16	42 8	41 5
17	41.3	40.3
18	—	—
19	—	—
20	42 0	39 0
4 Teeth		
16	—	—
17	45	42 2
18	47 5	41 6
19	44 5	48 5
20	—	—
4 shafts of long bone (2 femurs + 2 tibias)		
16	22 4	24 2
17	26 8	26 3
18	26 2	25.3
19	19 4	24 0
20	20 6	19
8 ends of long bones (2 femurs and 2 tibias)		
16	55 5	59 5
17	53 5	51 0
18	58 2	59 5
19	49 0	53 0
20	55 2	56 0

as the whole rat one week after injection is shown in Table XXII The two independent methods of determining bone specific activity show good agreement

3 Kinetic Studies with 'Ca in Man

The results of one of the dilution studies are shown in Figure 13 where the curve represents the Ca abundance in urine calcium relative to ' Ca abundance in 4 standard samples Normal abundance of 0 0032 % ' Ca is taken as 100 % For comparison the per cent dose Ca administered *per Gm calcium in the samples is shown in the right of the figure*

The presence of many other nuclides in samples activated for such a long period of time complicated the measurement of ' Ca in these

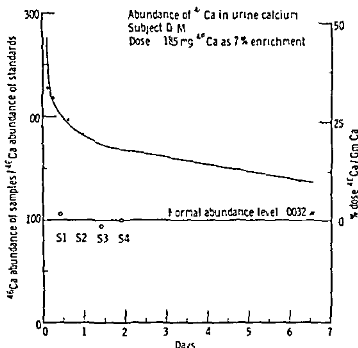


FIGURE 13

samples A simple post radiation radiochemical separation using a Ca spike would simplify the counting procedure and improve precision

Despite these counting difficulties the pattern of the curve in the case shown demonstrates that 'Ca may also be used as a stable tracer of calcium

C Normal Abundance of ' Ca

Table XX shows the Ca abundance level of samples isolated from bone and urine expressed as a ratio of the abundance of ' Ca in samples of Primary Standard Reagent Grade CaCO (Mallinckrodt 4071)

Little variation in abundance of Ca is apparent in these biological samples

IV DISCUSSION

A Determination of Abundance Levels of Ca and Ca

Stable isotopes of calcium can be used as tracers in vivo Mass spectrometry provides a precise method for determination of abundance levels of Ca and 'Ca in samples of calcium which can be easily iso-

lated from biological materials by oxalate precipitation Samples of 1 mg are sufficient for such analysis

'Ca and 'Ca may be activated to produce radioactive "Ca and 'Ca by neutron bombardment of samples from 5 to 10 mg in mass "Ca has a large cross section for neutron capture so that very short (1 minute) exposure to a neutron flux activates sufficient 'Ca so that precise counting can be performed in a short period (1—2 minutes) The short half life (8 7 minutes) of "Ca is not a problem as the sample can be counted immediately upon ejection from the reactor tube The high gamma ray energy (3 1 MeV) of 'Ca removes the problem of interference from other isotopic species which may contaminate the sample

Precision in 'Ca estimation in the contents of sealed polyethylene capsules plus precision in the estimation of total calcium in the same samples by EDTA titration make possible accurate abundance level determinations in samples collected following injection of enriched stable Ca

Ca has a much lower abundance and a much smaller cross section for neutron capture than Ca so that samples of 5—10 mg calcium must be exposed to a neutron flux for a period of several days to activate enough "Ca for precise counting This long period of activation produces other isotopes which make counting of the "Ca more difficult Despite some difficulties with this part of the assay it was possible to construct specific activity curves using calcium isolated from urine of human subjects injected with enriched ' Ca A radiochemical post radiation separation of calcium from the sample would improve the precision of this technique

The present relatively high costs of both enriched isotopes as well as the cost of activation can be expected to decrease markedly with development of further applications of stable calcium tracers

B Kinetic Studies with Ca and 'Ca

Parallel studies conducted in human subjects and in animals show that 'Ca and Ca are similarly distributed in the body Specific activity data derived independently showed good agreement of values for the two isotopes in both urine and bone over a wide range

Higher enrichments of "Ca are available but are relatively more expensive In the 2 human subjects the 10 4 % enrichment of ' Ca used meant that each patient received approximately 40 mg of natural calcium containing the 4 0 mg of ' Ca which was the actual tracer This however given slowly intravenously would not be expected to cause any untoward clinical reactions and did not seem to affect the observations

of specific activity compared to data derived from the parallel dose of Ca

The tracer doses of ' Ca given as its 7 % enrichment were contained in less than 3 mg of natural calcium per dose. This amount of natural calcium should not affect equilibrium in small animals.

C. Normal Abundance of "Ca

Since isotopic effects are known to exist where there are large differences in the mass of the various isotopic species of an element, the reliability of tracer studies with stable isotopes depends upon knowledge of the normal abundance of the isotopes in the system to which the tracer is added.

Corless (1964) has reported differences in Ca/' Ca ratio of ± 5—8 % in samples of calcium isolated from sea water, shell, rock and human teeth. Corless used neutron activation analysis with measurement of the 'Sc decay product of 'Ca and EDTA titration of total calcium in an other aliquot. The complex separation procedures used could conceivably introduce errors in such a method for abundance determination.

The studies of normal urine calcium, rat bone, human bone and standard calcium carbonate done by this method with direct EDTA titration of calcium in the activated samples did not show the large variations of Ca/"Ca abundance reported by Corless (1964).

V. CONCLUSIONS

Changes in the abundance of stable isotopes following the administration in enriched form as tracers may be followed as a measure of the specific activity of the stable tracer.

Parallel studies in man and in animals with Ca and Ca show that those two tracers are similarly distributed and that specific activity of the stable isotope is similar to that of the radioactive isotope in samples of calcium isolated from both bone and urine.

Kinetic studies with Ca in man show that this stable tracer may be used in the same way as "Ca. It possesses advantages in its much lower abundance and refinements in post radiation treatment of samples can be expected to increase the precision of this method.

Studies with Ca show that the normal abundance of this isotope and the increase following tracer doses can be quantitated by neutron activation analysis combined with total calcium determination performed directly on the activated samples.

Estimation of the Exchangeable Calcium Pool in Children Using ^{48}Ca

I INTRODUCTION

The use of radioactive calcium isotopes in the investigation of calcium kinetics in man has been largely limited to studies in adults Relatively few studies have been performed in children although the observations of Bronner (1956) using ^{45}Ca and Hoffenberg (1964) using ^{47}Ca have drawn attention to differences in calcium kinetics related to growth Extension of these investigations has been prevented by a reluctance to use radioactive tracers in young children—particularly normal children

The treatment of certain bone diseases and the assessment of the efficacy of such treatment are of most importance during the growth period For this reason a method for the study of calcium kinetics in children would be of considerable value Parameters derived from the specific activity curves include the exchangeable calcium pool the rate of excretion in urine and the rate of removal of calcium from the pool by other mehanisms—fecal loss and deposition in bone

The enriched stable isotopes of calcium (^{46}Ca and ^{48}Ca) can be used as tracers in such studies Abundance changes produced by injection of the enriched isotope are a measure of specific activity in samples from the system following injection. The principles of the use of stable calcium isotopes have been described and the validity of the method demonstrated in parallel studies with ^{47}Ca and ^{48}Ca in man and animals (See Chapters II III)

This report describes the use of stable ^{48}Ca in studies of calcium metabolism in 10 children

II MATERIALS AND METHODS

A Subjects

The 10 children studied were patients on the Children s Orthopaedic Service of the Hospital for Special Surgery Their ages weight ideal weight for age and diagnoses are shown in Table XXIV Case H 3 (osteogenesis imperfecta tarda) and case H 5 (bilateral Legg Perthes disease) were

TABLE XXIII Children studied using Ca as a tracer

Case No	Name	Age (years)	Sex	Weight (kg)	Ideal Weight (kg)	Diagnosis
H 3	R R	12.25	F	26.9	38.3	Osteogenesis imperfecta tarda healing fracture of the femur confined to bed
H-4	R D	10.0	F	49	31.9	Meningomyelocoele soft *tissue surgery of feet*
H 5	M C	7.5	M	30.5	25.9	Bilateral Legg Perthes disease confined to bed
H 6	D H	12.6	M	37.5	42.2	Post polio paresis of leg soft tissue surgery
H 7	*A H*	*10.8*	F	44.5	35.7	*Mild spastic paraplegia* soft tissue surgery
H 8	M D	7.25	M	37.2	24.5	Mild spastic paraplegia soft tissue surgery
H 9	A P	8.2	F	19.2	26.4	Congenital hypoplasia of leg muscles possibly post polio soft tissue surgery
H 10	S G	8.2	F	31	26.4	Mild spastic paraplegia soft tissue surgery
H 11	S F	10.2	M	22.7	31.9	Mild spastic hemiplegia soft tissue surgery
H 12	D B	8.5	F	42.2	[illegible]	Mild spastic quadriplegia soft tissue surgery
Mean ± S D		(9.5 ± 1.9)		(34.1 ± 8.8)	(31.1 ± 6)	

the only cases with recognized disturbances of bone metabolism The remaining 8 cases were admitted for a variety of soft tissue surgical procedures usually tendon transfers or release of muscle contractures in the management of moderate locomotor handicaps secondary to polio *or cerebral palsy*

The ages ranged from 7.25 to 12.6 years with a mean age of 9.5 ± 1.9 years Weights ranged from 19.2 to 49.0 kg with a mean weight of 34.1 ± 8.8 kg The ideal weights for age and sex (Nelson 1954) are also listed in Table XXIII for comparison

During the studies the children consumed a normal hospital diet Except for cases 3 and 5 who were confined to bed the children were usually in later stages of convalescence from surgery and were quite active

B Procedure

1 Tracer Dosage

a *Preparation of Stable "Ca Tracer Dose*

Pure $CaCO_3$ containing 'Ca as its 39 72 % enrichment was dissolved in 1 N HCl and diluted with water by weight to make a solution containing 5 0 mg natural calcium per Gm as $CaCl_2$ at pH 5 0 which was sterilized by autoclaving *The solution contained 1 98 mg "Ca per Gm* Two ml disposable plastic syringes were weighed before and after injection of the tracer to allow precise quantitation of the dose given

b *Calculation of Dose*

The normal abundance of Ca in nature is 0 179 % of total calcium One Gm natural calcium thus contains 1 79 mg "Ca

The dose given each child was about 4 0 mg 'Ca (exact dose in each case listed in Table XXV) *For example this amount would raise the* abundance in a 1 Gm calcium pool by 223 per cent *above the normal abundance level* corresponding to an abundance of $\frac{4\ 0+1\ 79}{10} = 579\ \%$ 'Ca

c *Administration of Isotope*

As the specific activity measurements were based upon the 'Ca abundance levels in timed urine samples collected in the period following injection all subjects voided just prior to receiving the 2 Gm dose of 'Ca solution by injection in the antecubital vein *Since the dose of 2 Gm* contained a total of 10 mg of natural calcium it was given slowly over a period of not less than one minute

2 Urine Collection

The subjects voided at their usual times each entire specimen was placed in a clean acid washed glassbottle and labelled with the date and time period of the collection A record of voiding times was also maintained *In this way the occasional loss of a specimen did not compromise* the specific activity determination on the samples preceding or following it

C Methods (Methods are described in detail in Chapter III)

1 Isolation of Calcium from Urine

*All samples were acidified to pH <3 0 with 10 N HCl and shaken thor*oughly Because of the frequency of voiding in some subjects samples were combined to give collection periods approximating 12 hours for

the first two or three days and 24 hours thereafter for 5 to 8 days An aliquot was kept aside for total calcium titration Calcium was isolated using a double oxalate precipitation

2 Ca Abundance Measurement

The 'Ca content of ten mg samples of Ca as $CaCO_3$ isolated from urine was determined by neutron activation analysis at the Union Carbide Research Reactor Tuxedo Park N Y through the cooperation of Dr W Wahl (1964) and Mr H Nass (1964) Total calcium of the activated sample was determined by EDTA titration permitting calculation of Ca abundance in samples and standards

3 Calculations

The Ca/' Ca ratio of each sample relative to the Ca/' Ca ratio of standards was a measure of the increase of abundance in the samples due to the tracer dose of enriched Ca

For example

Where a dose of 4 0 mg Ca had been given the increase in 'Ca abundance if 100 % of the dose were in 1 Gm calcium would be 223 % *above* the normal level of 179 % 'Ca

If a sample from that patient revealed a Ca abundance level which was 122 % of that in the standards then the 22 % increase over normal related to the 223 % increase due to 100 % dose meant that the specific activity of that sample was $\frac{22}{223} \times 100$ or 10 percent dose Ca/GmCa

III RESULTS

A Ca Abundance Increase in Samples

There were no difficulties in the measurement of Ca content of the activated samples as the induced radioisotope Ca ($T_{1/2}$ 8 7 minutes)

The abundance levels of Ca in samples were expressed as a percent of the Ca abundance of standards used for each series of samples activated The Ca abundance of calcium standards (Primary Calcium Standard CaCO Mallinckrodt 4071) was a constant value within each series activated however the apparent values varied between series since they were related to weighed standards used routinely at the Reactor Thus the apparent Ca abundance of our internal standards would be 182 for one series (see Table XV) and as high as 195 in a later series activated yet the source of calcium was the same Relating all sample abundance values to the standard source of calcium (Pri

5—McPherson

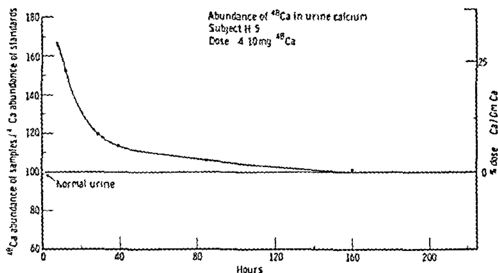


FIGURE 14

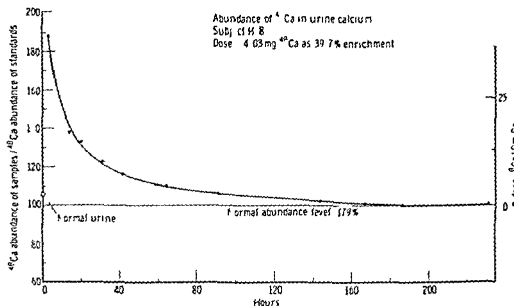


FIGURE 15

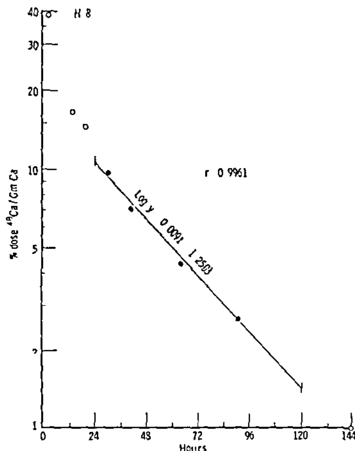


FIGURE 16

mary Standard CaCO Mallinckrodt) and giving this the value 179 % Ca abundance (White and Cameron 1948) permitted comparison between cases in terms of percent Ca abundance increase

Table XXIV contains the data of each case studied listing the dose of Ca administered the percent abundance increase that 100 % dose would have produced in 1 Gm and the % abundance increase noted in calcium isolated from urine at the mid points of urine collections both prior to injection (Time 0) and in the several days following injection

Figures 14 (case H 5) and 15 (case H 8) illustrate the change of Ca abundance in urine calcium with time The curve demonstrates the return to normal abundance levels by 5 to 6 days after injection

These representative curves also demonstrate normal Ca abundance prior to injection compared with the level reached by the decline of the specific activity curve The 100 % abundance level is that of the Primary Standard Calcium (Mallinckrodt 4071) used as a reference standard in each series of samples activated

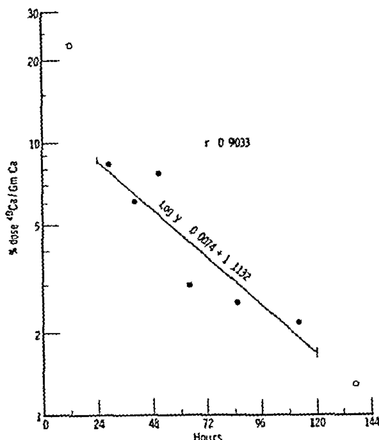


FIGURE 17

B Ca Specific Activity

When the Ca specific activity of urine samples (Table XXIV) was plotted logarithmically against time there appeared to be a sharp fall of specific activity during the first 15 to 20 hours followed by a monoexponential fall of specific activity in the period between 24 and 120 hours

Using least squares analysis and employing the values for specific activity between 24 and 120 hours equations were found to represent this portion of the curve for each case The equations and correlation coefficients are shown in Table XXIV Examples are shown in Figures 16 and 17

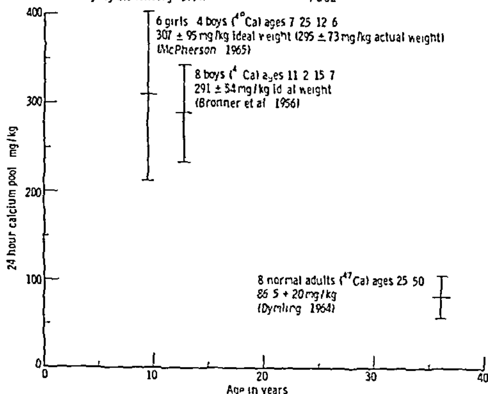


FIGURE 18

C Estimation of 24 Hour Exchangeable Calcium Pool

The reciprocal of the 24 hour Ca specific activity expressed in Gm was used as a measure of the exchangeable calcium pool The specific activity value used was taken from the equation derived by least squares analysis on the values between 24 and 120 hours

The pool sizes for each case as absolute values in Gm and as they relate to body weight are given in Table XXIV The mean exchangeable calcium pool size in the 10 cases studied was 9 34 ± 2 29 Gm When related to ideal body weight the pool size was 307 ± 95 mg/kg and when related to actual body weight the pool size was 295 ± 73 mg/Kg

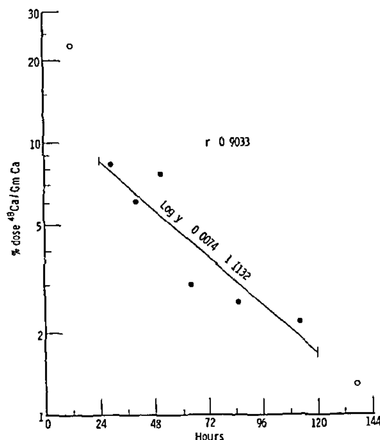


FIGURE 17

B ' Ca Specific Activity

When the "Ca specific activity of urine samples (Table XXIV) was plotted logarithmically against time there appeared to be a sharp fall of specific activity during the first 15 to 20 hours followed by a monoexponential fall of specific activity in the period between 24 and 120 hours

Using least squares analysis and employing the values for specific activity between 24 and 120 hours equations were found to represent this portion of the curve for each case The equations and correlation coefficients are shown in Table XXIV Examples are shown in Figures 16 and 17

TABLE XXIV Data from ^{44}Ca kinetic studies in ten children

Case No	Total Dose ^{44}Ca (mg)	Abundance for 100 dose in 1 Gm	Time Hours (x)	Per cent of normal abundance	Specific Activity dose ^{44}Ca/Gm Ca (y)	24 hour Specific Activity dose ^{44}Ca/Gm	24 hour Pool size Gm (Reciprocal of 24 hour Spec activity)	24 hour Pool (mg) / Body wt (Kg)	Mean urine Ca loss Mg/day
II 3	342 mg	291 7	2 0	136	18 9	10 5	9 46	249	59
			18 1	130	15 7				
			48	112	6 3				
			73	106	3 14				
			95 8	104	2 1				
			131	100	0				
			143	102	1 05				
			180 5	102	1 05				
			201 5	99	0				
			log y=—010 x+1 2632 r=—9927						
II 4	382 mg	314 7	0	98	0	1 59	6 27	196	40
			25 5	125	11 7				
			45	120	9 4				
			57	111	4 9				
			68	113	6 8				
			81	110	4 7				
			93	98	0				
			135	101	4				
			161	104	1 8				
			log y=—0131 x+1 5150 r=—8497						

Case No.	Total Dose 44Ca (mg)	Abundance for 100 dose in ...	Time Hours (x)	Per cent of normal abundance	Specific Activity dose 44Ca/ ... Ca (y)	4 hour Specific Activity dose 44Ca Cm	24 hour Exchangeable Cm (Reciprocal of 24 hour Spec. Activity)	24 hour Pool (mg) / Body wt (kg)	Mean urine Ca loss Mg/day
H 5	410 mg	330 %	0	100	0	8 0	11 0	450	200
			12	152	22 0				
			29	110	8 3				
			39	111	6 1				
			51	118	7 9				
			61	107	3 0				
			85	100	2 6				
			113	105	2 2				
			137	103	1 3				
			160	101	4				
			184	102	9				
			log y = — 0054 x + 1 1132		r = — 9033				
H 6	401 mg	316 %	0	106	0	8 4	11 9	283	80
			1	211	49				
			5	141	19 2				
			9	132	11 2				
			28	113	5 8				
			39	111	4 9				
			52	108	2 7				
			71	104	1 3				
			91	109	4 0				
			131	103	1 1				
			181	98	0				
			198	98	0				
			log y = — 0221 x + 1 6312		r = — 8149				

Case No	Total Dose ⁴⁵Ca (mg)	Al un lance for 100 lo e in 1 (n	Time Hour (x)	I er c nt of normal al un lanc	Sp cific A tl ity I e ⁴⁵Ca/ Cm Ca (y)	24 Hour Specific Activity dose ⁴⁵Ca/Ct	24 H ur Io I size Cm (R Iprocal of 24 hour Spec Activity)	24 H ur I ol (mg) / H I wt (1 g)	Mean urine Ca lo s Mg/ lay
H 7	4 14 mg	331 %	0	100	0	8 8	11 4	319	185
			1	131	13 4				
			4	164	27 7				
			10	1 3	22 9				
			29 5	121	9 1				
			41	116	6 9				
			51	107	3 9				
			111	101	1 7				
			1 7	103	1 3				
			181	10?	9				
			203	100	0				
			log y = — 0091 x + 1 137		r = — 9630				
H 9	4 03 mg	?? %	0	106	2	10 8	9 3	380	80
			3 5	187	38 7				
			14	138	16 9				
			?0	133	11 7				
			31	12?	9 8				
			41 5	116	7 1				
			64	110	4 4				
			91	106	2 6				
			143	102	1				
			166	101	5				
			180	100	0				
			231	101					
			log y = — 0091 x + 1 2 03		r = — 9961				

Case No	Total Dose 45Ca (mg)	Abundance for 100 dose in 1 Gm	Time Hours (x)	Per cent of normal abundance	Specific Activity ÷ dose 45Ca/Gm Ca (y)	24 hour Specific Activity dose 45Ca/Gm	24 hour Pool size Gm (Reciprocal of 24 hour Spec Activity)	24 hour Pool (mg) / Ideal wt (kg)	Mean urine Ca loss Mg/day
H 9	4 10 mg	329 %	0	102	1	12 5	8 0	301	57
			4	245	63				
			17	150	21 9				
			29	121	9 2				
			53	119	8 2				
			80	110	4 3				
			100	104	1 9				
			126	105	2 1				
			144	101	1 7				
			170	100	0				
			190	100	0				
			214	98 1	0				
			log y = — 0093 x + 1 3180		r = — 90[illegible]5				
H 10	4 12 mg	330 %	0	98 5	0	16 1	6 2	236	186
			5	226	[illegible]				
			14	155	24				
			21	137	16 4				
			61	112	5 2				
			76	118	7 8				
			88	107	3 0				
			99	106	2 6				
			123	103	1 3				
			136	104	1 7				
			160	101	5				
			170	97	0				
			log y = — 0101 x + 1 4481		r = — 9170				

Case No	Total Dose Ca (mg)	Al un lance for 100 lose in 1 Cm	Time Hours (x)	Per cent of normal abundance	Specific Activity Dose ⁴⁵Ca/Cm Ca (y)	24 hour Specific Activity Dose ⁴⁵Ca/Cm	24 hour Pool size Cm (Reciprocal of 24 hour Spec Activity)	24 hour Pool (mg) / Total wt (kg)	Mean urin Ca loss mg/day
II 11	4 09 mg	3?8 %	0			15 8	0 4	19?	10›
			3	252	66 ›				
			15	171	31				
			27	133	14 5				
			47	127	11 8				
			69	115	6 6				
			89	117	7 1				
			101	10)	3 9				
			141	112	5 3				
			1ᴊ9	106	2 6				
			log y = — 0069 x + 1 3038		r = — 933?				
II 12	4 18 mg	333 %	11	133	14 1	7 8	12 8	400	100
			17	133	14 1				
			?3	1?9	12 1				
			33	118	7 7				
			42	11ᴊ	6 5				
			ᴊᴊ	114	6 0				
			67	107	3 0				
			8?	106	2 6				
			113	106	3 0				
			143	10ᴊ	2 0				
			1ᴊ6	103	1 0				
			180	100	0				
			log y = — 00ᴊ0 x + 1 0346		r = — 8603				

General Discussion

The measurement of stable isotopes by neutron activation and counting of induced radionuclides combined with estimation of total element by chemical means permits the use of certain stable isotopes as tracers

The use of enriched stable isotopes has been described in studies of iron metabolism (Lowman and Krivit 1963) and calcium kinetics (McPherson 1963)

This investigation describes the application of ^{46}Ca and ^{48}Ca as tracers of calcium in man and animals The abundance of ^{46}Ca and ^{48}Ca is determined in 10 mg samples of calcium using activation analysis and measurement of the induced radioisotopes ^{47}Ca and ^{49}Ca by gamma spectrometry combined with direct EDTA titration of total calcium in the activated samples Simple chemical procedures are adequate to remove interfering elements prior to activation of ^{48}Ca

Studies of the ^{48}Ca specific activity ratio between serum and urine in man failed to demonstrate a biological isotope effect fractionation of heavy calcium isotopes is not of such degree that it affects calcium tracer studies The 10 mg samples for activation can thus be isolated from timed urine collections and are representative of the isotopic abundance pattern of serum

Abundance increase of the stable isotope in samples relative to the abundance increase which the total dose would have produced may be expressed as specific activity of the stable isotope Parallel studies in man and animals show that the specific activity values of stable (^{48}Ca) and radioactive (^{47}Ca) isotopes are similar

The dose of stable isotope used is calculated in relation to the expected pool size length of study enrichment of isotope available and the amount of calcium in the dose which may affect equilibrium in the system studied In this regard the low natural abundance of ^{46}Ca is an advantage

^{46}Ca used as a tracer in children has permitted estimation of the exchangeable calcium pool 24 hours after injection Application of stable calcium tracers to the estimation of this as well as other parameters of calcium kinetics in such radiosensitive subjects should lead to an increased understanding of the physiology of skeletal growth

General Summary and Conclusions

CHAPTER I *Direct EDTA titration of Calcium and Magnesium in Biological Samples*

1 A direct recorded EDTA titration procedure permits precise measurement of total calcium and total calcium plus magnesium giving magnesium by difference in a variety of biological materials

2 Phosphate interference during titration is prevented by addition of citrate in excess

3 The normal range of serum calcium and serum magnesium is very narrow (9 50 ± 0 35 mg% and 2 24 ± 0 21 mg% respectively)

4 Precision in estimation of total calcium in small samples has permitted the use of this method in the determination of the abundance of stable calcium isotopes used as tracers of mineral metabolism using neutron activation analysis

CHAPTER II *Heavy Calcium Isotopes as Tracers of Calcium*

1 Differences in blood and urine specific activities could not be demonstrated in three human subjects

2 The abundance of Ca in a variety of biological samples was constant

CHAPTER III *Ca and Ca as Tracers in Studies of Mineral Metabolism*

1 Procedures for the determination of Ca and Ca abundance in biological samples using neutron activation analysis and EDTA titration of total calcium permit the use of enriched isotopes as tracers

2 Simultanous tracer studies with Ca and Ca show agreement

CHAPTER IV *Estimation of the Exchangeable Calcium Pool in Children Using Ca*

1 Ca in enriched form was used as a tracer in dilution studies of calcium kinetics in 10 children

2 Changes in Ca abundance levels in samples of calcium isolated from timed urine collections determined by neutron *activation analysis* reflected specific activity in per cent dose/Gm calcium

3 The 24 hour exchangeable calcium pool relative to body weight is 3 to 4 times as high in the children studied as in normal adults

ACKNOWLEDGEMENTS

Financial support was obtained from the Alfred Österlund Foundation and the Polio Foundation, Sweden; from the U.S. Public Health Service, National Institute of Dental Research (Contract Nr D 1452), U.S. Public Health Service Training Grant AM 5414, the Atomic Energy Commission (Contract Nr AT (30-1) 3234), the Josiah Macy Jr Foundation, the Whitehall Foundation and the Evelyn Sharp Foundation, United States; from the Medical Research Council of Canada (Graduate Medical Research Fellowship), and from the International Atomic Energy Agency (Contract Nr 50), Vienna.

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From the Department of Human Anatomy (Head Professor Bo E. Ingelmark, M. D.)
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CONTENTS

INTRODUCTION

The mechanics of the human locomotor system as revealed by purely mechanical techniques have attracted increasing interest during recent decades Because of the difficulty in obtaining fresh material most studies have been performed on autopsy material which has been stored for varying lengths of time In order to evaluate the results of such studies one must determine whether postmortal changes affect the mechanical properties of various tissues

Many authors have mentioned the problem but only a few have investigated it The results are contradictory great differences having been recorded concerning mechanical properties of tendons and ligaments The number of tests made has often been inadequate and the terminology used confusing thus making comparisons difficult The authors therefore felt that it would be useful to determine how long a period of time must elapse after death before one must consider the influence of postmortal changes on results

The aims of the study have been (1) to investigate qualitatively the mechanical characteristics especially tensile strength of the anterior cruciate ligament of rabbits (2) to determine how these physical properties are influenced by postmortem changes and (3) correlate the results *with the histological picture*

The following symbolics and units of recording are used throughout the text

Load P in kp (9 80665 kg m/s)

Elongation Δl in mm

Area A in mm

Tensile stress σ in kp/mm

Strain ε in $\frac{\Delta l}{l}$ (dimensionless)

Energy W in kpmm

All through the statistical analysis a level of significance of 5 per cent has been applied

SURVEY OF THE LITERATURE

Mechanical properties of ligaments

Reutervall (1921) performed experiments on the ligamentum nuchae from human cadavers and found an elastic after effect of 4 per cent. He also found similar properties in tendons. He noted that collagenous and elastic fibres in a relaxed preparation lay in a wavy formation and considered this to be of importance to the distensibility curve.

Investigating knee joint ligaments in the dog, Annovazzi (1928) came to the conclusion that they were extensible when loaded and within certain limits elastic. He showed that ligaments containing elastic fibres had a lower elastic limit than those consisting solely of collagenous fibres.

Hardy (1951) in a study on the ligamentum patellae of the cat and the human ligamentum flavum and calcaneo navicular ligament, found no extensibility in »collagenous« ligaments but 140 per cent extensibility (of its unstretched length) in »elastic« ligaments. As his methods and results are not presented his observations are difficult to evaluate.

Smith (1954) experimented on the anterior cruciate ligament of the rabbit and concluded (1) that the failure load of the ligament was related to the weight of the animal, (2) that the temporary extensibility was 20 per cent of the original length of the ligament and (3) that the ligament was elastic to a load in the order of body weight but to submaximal loads only when of short duration. He found a relationship between body weight and failure load but did not consider it uniform enough to permit calculation of an individual ligament's failure load.

Steindler (1955) reviewed physical properties of the locomotor system. He believed that those ligaments which under normal motion are especially exposed to tensile stresses should be largely composed of elastic fibres. According to this believe the ligamenta flava for example should be hypertrophied when the spine is unstable. If the stress is excessive or too prolonged a ligament should become relaxed and loose its elasticity. He thought that tendons and fascia might react similarly.

Mechanical properties of other soft connective tissue structures

Wertheim (1847) investigated the mechanical properties of tendons among other parts of the human body. He used fresh preparations from bodies aged one to seventy four years. He found that the load elongation curves of the tendons resembled a hyperbola with the vertex in the

origin For bone the curve was a straight line through the origin With drying the modulus of elasticity increased and the shape of the curve approached that of bone

Gratz (1931) found that human fascia lata had »high elastic properties« and claimed that the presence of excessive fatty tissue might interfere with their elasticity as well as their viability

A classical clinical and experimental study on the biomechanics was made by McMaster in 1933 In the experimental part of his work he loaded the calcaneus—tendo Achilles—m gastrocnemius—femur—complex Only when half of the tendon was cut through he did obtain a tendon rupture in the other cases a tendon muscle junction rupture or a bone fracture occurred He concluded that the normal tendon was not the weakest point of the system investigated

Cronkite (1936) tested the tensile strength of a great number of *human tendons Each tendon was held by a pair of clamps designed* to prevent slipping and was fixed in a standard testing machine of the type used by engineers The results showed very great variations in the tensile strength of different tendons from the same body and of the same tendon from different cadavers The tensile strength ranged from 8700 to 18000 pounds per sq inch in different cadavers and in the case of individual cadavers the maximum value was as much as three times the minimum value Hence Cronkite stated that it was futile to establish a norm of tensile strength for tendons in general

Stucke (1950) studied human Achilles tendons He found that this tendon had its highest elasticity in the third decade of life The degree of elasticity however showed an obvious fall with age after this period He reproduced stress strain curves and found a tendency to decreased *extensibility at 0 89 kp/mm and 41 per cent of the maximal extension* He gave the maximum figures of 4 67 kp/mm and 7 34 per cent *elongation*

Hill (1951) stated that tendons of muscles were extensible and elastic but did not specify his methods or results

Dick *(1951)* tested the reaction of human skin under pressure and studied the histological picture He concluded that it is reasonable to correlate the initial tensions in the skin with the condition of the yellow elastic fibres« In an experiment on fascia lata and dura mater he compared them with rubber and suggested that white collagenous fibres by themselves respond to distension as does rubber

The tensile strength of the special connective tissue developing in a healing skin wound has been studied by Sandblom (1944) and Sand

blom Petersen and Muren (1955) More recently studies have been made by Sandberg and Zederfeldt (1963)

Postmortal changes of mechanical properties of ligaments

Wertheim (1847) tested a tendon from a dog immediately after death and five days later its remaining counterpart which had been stored and found no difference in the modulus of elasticity

Annovazzi (1931) found that the physical properties of knee joint ligaments of dogs changed rapidly after death

Gratz (1931) tested human fascia lata obtained at operations after two to eighteen hours storage in salinemoistened gauze He noted that after eighteen hours delay the material »was essentially alive« No figures are given and there is no mention of any differences or similarities

Cronkite (1936) tested the tensile strength of human tendons a few of them twenty four to forty eight hours after death and un embalmed the remainder embalmed and ten to eighteen months old He noted that the old tendons differed little in strength from the others

Akerblom (1948) found that the extensibility and elasticity of human ligamenta flava were practically unaltered after unprotected storage in a refrigerator for an unspecified time However he based his statement on a single specimen

Stucke (1950) in his investigation on the elasticity of human Achilles tendons compared relatively fresh amputation and autopsy material with material fixed for some time in 10 per cent formalin finding every individual peculiarity lost in the latter group To eliminate the time factor his tests were performed within six hours after removal from the body

Hardy (1951) stated that an »elastic ligament« lost its characteristic physical properties within one hour after death and that after five hours no extension occurred on a load of fifty six pounds The statement was based on one human calcaneo navicular ligament from an amputated leg fixed in formol saline It is considered that his conclusions from the presented data are not fully justified

Smith (1954) stated that as soon as one hour after death ligaments became less readily extensible i e the modulus of elasticity increased and reacted elastically to greater loads The changes then became progressive In his investigations he set the limit for fresh ligaments at thirty minutes He gave no figures on the postmortal changes

The stress strain relationship of human embalmed plantaris tendons was investigated by Walker Harris and Benedict (1964) They found the tensile strength of dried tendons to be higher than that of moist ones

Some work on the mechanical properties of tendons subjected to irradiation has been done Braams (1961) found that the presence of water reduced the sensibility of the material to radiation i e decrease of the tensile strength was less Ashley and co workers (1964) found that irradiated tendon grafts functioned as satisfactorily as the non irradiated ones

In some works on allied structures postmortal changes are mentioned

Evans and Lissner (1959) in a study on biomechanics of the human lumbar spine and pelvis obtained at autopsy noted that embalming tended to harden and stiffen the specimen and to increase the average maximum load

Hardy Lissner Webster and Gurdjian (1959) in their study on loading tests on the lumbar spine used refrigerated embalmed and deepfrozen specimens but noted no apparent effect due to the varying storage methods

Studying lumbar intradiscal pressure Nachemson (1960) stored the specimens in a refrigerator and a deep freezer He stated that it was impossible to ascertain whether any postmortal changes had occurred and if so the changes were not uniform

MATERIALS AND METHODS

Materials

The material in the present study has been obtained from the cruciate ligaments of the knees of rabbits weighing between 2050 and 4200 gms Only adult animals have been used to avoid influence of uncalcified epiphysis upon the shape of the load elongation curve Closure of the distal femoral and proximal tibial epiphyses has been checked at X ray examination

The anterior cruciate ligament has been used for the mechanical tests The anterior cruciate ligament before and after testing as well as the corresponding posterior ligament have been taken for the histological studies A test specimen consists of the ligament with its bony

attachment at each end thus constituting a complete functional unit (bone ligament bone) The test specimens are arranged in six groups according to the length of time between killing of the animal and testing These are a »fresh« group and groups which have been stored for 2 6 24 48 and 96 hours between killing and testing Each group contains both knees of four animals In addition there are six single knees in the »fresh« group coming from successful preliminary experiments and they are included in the material when calculating the mean values given in Table 2 8 further knees from 4 rabbits are included in the 6 hour group in order to elucidate a marginal case in the statistical analysis (cf p 26)

The rabbits in the »fresh« group have been anesthetized with four ml 25 per cent urethane subcutaneously and 0 5 ml 10 per cent allypropymalum intravenously per kg body weight to enable both knees to be removed in vivo The soft tissues around the knee joint have been removed leaving only the capsule intact The femoral and tibial shafts are then severed at an appropriate distance from the joint and the capsule with the adjoining ligaments except the anterior cruciate ligament are excised The time lapse between ligation of the femoral artery and the end of the experiment ranges from eight to eleven minutes The tests have been made approximately two minutes after exposure of the ligament to air This group is subsequently called the 0 hour group

The animals in the other groups have been sacrificed by means of a heavy occipital blow and stored at 18 20° C until used

Testing and recording equipment

The materials testing machine used (Fig 1) consists of a truck on two horizontal rails which is pushed or pulled by the plunger of the hydraulic cylinder The fixed end of the testing system is a steel cylinder anchored to the rails The force is applied to the plunger by an electrically powered oil pump The activation and increase of the force are controlled by a system of valves By using the same valve settings for each experiment the application of load on the system is approximately uniform per time unit

The test specimen is attached to contoured clamps (Figs 1 and 2) capable of vertical and horizontal movement but not rotation The clamps are formed after the bone shape in order to prevent all slipping phenomena by the load application It is important to avoid rotation because the anterior cruciate ligament is twisted in situ giving the im

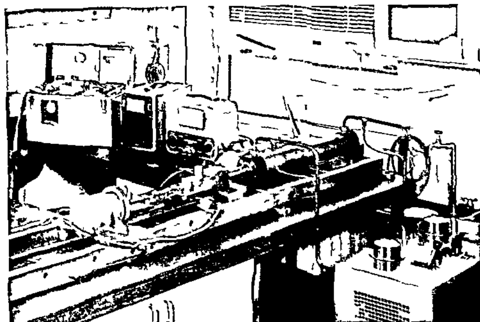


Fig. 1 The strength testing apparatus. On the table in the background there are from left to right the directwriting recorder and two bridges (one for load, the other for elongation). From the left on the table in the foreground there are the load pick up, the clamps holding the specimen, the plunger and hydraulic cylinder. To the right of this table there are the oil pump and its control panel.

pression that the tibial head has been rotated medially 90° in relation to the femur. If the ligament is allowed to unwind under stress a false elongation reading would be recorded. The clamps are attached to the fixed steel cylinder and the moving plunger respectively. Thus any movement of the plunger away from the cylinder would produce tensile strain and stress in the ligament between the clamps.

The load is recorded by the pick up consisting of four strain gauges coupled in complete bridge mounted inside a steel cylinder at the fixed end of the test bench, the pick up manufactured by Dietz. The distortion of the cylinder is caused by the actual tensile force and the effect on the strain gauges is indicated on a direct reading measuring bridge (Philips PT 1200).

The elongation of the whole system, i.e. the increase of the distance between the fixed steel cylinder and the plunger stretching the ligament (the only extensible structure), is registered by strain gauges cemented on a steel plate deflected by a vertical steel pin on the plunger (Fig. 1).

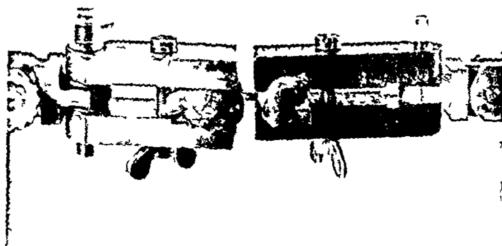


Fig 2 Close up of the clamps and test specimen showing from the left the distal end of the femur the anterior cruciate ligament and the proximal end of the tibia

The stretching of the strain gauges is indicated on a direct reading measuring bridge (Philips GM 5536)

Both bridges are connected with the Oscillomink which recorded load and elongation simultaneously on separate channels Fig 3

The whole system has been calibrated once prior to the commencement of the experimental series with the aid of tensiometers (Vibro Meter GM 11/S) for load and by a micrometer gauge for elongation The mechanical calibration has been checked from time to time and found to be correct

The electronic calibration of the system by means of built in electronic calibration signals has been carried out before each experiment Checks have been carried out immediately after the experiments on several occasions and the calibration has been found correct

The gain of the amplifiers in the recorder has been set to give one mm deflection for one kp load and five mm deflection for one mm elongation The recordings have been read under a lowpower dissection microscope For each kilopond load change the corresponding elongation has been estimated at one quarter of a millimeter on the

Fig 3 Curves obtained from the recorder in one test with elongation at top load in the middle and fifty c/s time markers at bottom

recording Thus eliminating the time axis tensile load elongation diagrams have been plotted where the zero point of elongation axis is set at five kp load except for the calculations of areas beneath the curve where zero is set at 0 kp load (Fig 4) At five kp load the structures

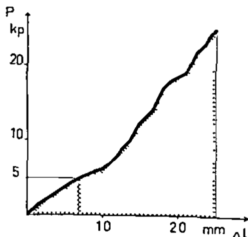


Fig 4 The load elongation diagram plotted from the recording illustrated in Fig 3 with load (P) in kp along the ordinate and elongation ($\triangle l$) in mm along the abscissa The shaded area represents the amount of energy required to rupture the specimen The outlined coordinates represent the five kp level

except the actual ligament are considered stretched and »fixed in tension« This has proved to be true Looking at the diagrams the curves of the »fresh« group are parallel and using the »five kp load equals 0 mm elongation —point the curves coincide

The error in the measurements have been studied by multiple measurements 16 in all Table 1 gives Karl Pearson s coefficient of variation (Kendall and Stuart 1958) which has been calculated from the series of measurements of the different components of the equipment The figures give the errors found in per cent The tensile strength pick up has been subjected to a standard load of 42 kp The elongation pick up has been deflected 4 mm and the pointer instrument has been read Both bridges have been unbalanced with a standard amount of resistance change and the pointer instruments have been read Both channels of the recorder have been subjected to standard variation of the input voltage and the recordings have been read as described before A constant area has been measured by the planimeter

	Measurement	
	load	elongation
Pick up + bridge	1 41	1 09
bridge	0 48	0 22
recorder	0 4[illegible]	0 32
planimeter	[illegible]	[illegible]

Table 1 The coefficient of variation for multip[illegible] [illegible] its with the [illegible] of the eq[illegible]

Mechanical basis of the stress strain

It is essential to d[illegible] [illegible] material s[illegible] [illegible] rties of a coherent system [illegible] [illegible] med uni[illegible] [illegible] unit [illegible] (mm) and the unit c[illegible] [illegible] [illegible] ponds) [illegible]

*) The force acting on [illegible] [illegible] o gram [illegible] m/sec = one kilopond [illegible]

The stress strain diagram is a useful means to illustrate a material s strength characteristics in both elastic and plastic ranges (Fig 5) Such a diagram should also be suitable for determining the mechanical properties of the anterior cruciate ligament studied here as well as the extent to which these may change with time after death

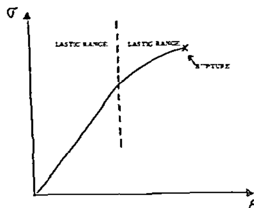


Fig 5 The type of stress strain diagram for an elastoplastic material

Such a diagram is generally valid when the material is stretched whatever its geometrical shape because the loading is defined by the stress (σ) which equals force per unit area and the strain (ε) which is the longitudinal deformation ($\triangle l$) per unit length (l_0) This diagram can be used for predicting a variety of properties of a body of any known shape such as its failure load elongation and the energy required to cause rupture

In order to construct such a diagram for a particular ligament one must be able to stretch it in the direction of its fibres determine corresponding values of load (P) and elongation ($\triangle l$) and know the original area (A) and length (l_0) of the ligament The relationship between load and elongation for the bone ligament bone complex may be found without undue difficulty in accordance with Fig 6 But owing to the fact that the ligament is disposed obliquely in relation to direction of the force the true force acting on the ligament will be the measured load times a factor greater than unity and the true elongation of the ligament will be the measured elongation times a factor less than unity In the case of the ligament studied here the elongation of the bone is negligibly small compared with the elon

except the actual ligament are considered stretched and »fixed in tension« This has proved to be true Looking at the diagrams the curves of the »fresh« group are parallel and using the »five kp load equals 0 mm elongation« —point the curves coincide

The error in the measurements have been studied by multiple measurements 16 in all Table 1 gives Karl Pearson s coefficient of variation (Kendall and Stuart 1958) which has been calculated from the series of measurements of the different components of the equipment The figures give the errors found in per cent The tensile strength pick up has been subjected to a standard load of 42 kp The elongation pick up has been deflected 4 mm and the pointer instrument has been read Both bridges have been unbalanced with a standard amount of resistance change and the pointer instruments have been read Both channels of the recorder have been subjected to standard variation of the input voltage and the recordings have been read as described before A constant area has been measured by the planimeter

	Measurement	
	load	elongation
Pick up + bridge	1 41	1 09
bridge	0 48	0 22
recorder	0 45	0 32
planimeter	0 11	

Table 1 The coefficient of variation for multiple measurements with the components of the equipment

Mechanical basis of the stress strain diagram

It is essential to discuss a material s mechanical properties in terms of a coherent system of well defined units The metric unit of length (mm) and the unit of force kp (kiloponds)*) have been adopted

*) Th[illegible] a[illegible] on the mass of one kilogram subjected to a gravity of 9 80665 m[illegible] kilopond

conclusion In his experiments on healthy Achilles tendons from cats and rabbits Davidsson (1954 and 1956) never obtained a tendon rupture but found that the tendon became detached from its origin or its insertion or a femoral fracture occurred Rupture of the Achilles tendon was not obtained in normal frogs (Fink and Wyss 1942) nor in the corresponding tendons of dogs (Stucke 1951)

With the aid of the load elongation diagram one can observe the following characteristic quantities

1 The *ratio* $\frac{P}{\Delta l}$ which should be constant within the elastic range and, if so equals the slope or tan α (corresponds to the modulus of elasticity $E = \frac{\sigma}{\varepsilon}$ in the stress strain diagram)
2 The *failure load,* P_{max}
3 The *elongation at rupture* Δl_{max} and
4 The *failure energy* W_f corresponding to the area between the curve and the Δl axis or expressed mathematically

$$W_f = \int_0^{failure} P \; d(\Delta l)$$

In the case of a ligament tan α is the most significant quantity because a ligament probably normally works in the elastic range and never approaches the failure point Nevertheless if it is desired to evaluate the risk of overstraining the ligament the quantities P_{max} Δl_{max} and W_f are most useful

Abrupt deflections of the curve denote that discontinuous processes are taking place in the ligament i e that some fibres are rupturing and forcing the remaining intact fibres to carry the load Accordingly a smooth load elongation curve means that the individual fibres of the ligament are of uniform quality with respect to tensile strength

Another explanation of the deflections would be slip phenomena at the ends of the specimen but slip of that order is avoided by using contoured clamps

Yielding i e structural changes do not cause load decrease but longer or shorter periods of constant load

RESULTS

Gross shape of load elongation curves

Roughly three types of load elongation curves could be distinguished according to their shape The largest group comprised more or less

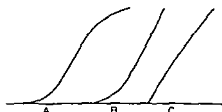


Fig 7 Three typical shapes of the load elongation curve

S shaped (sigmoid) curves having a rather shallow or flat initial portion a steeper and linear intermediate portion and a more level final portion the latter sometimes exhibiting a marked curvature (Fig 7 A) A somewhat smaller group commenced similarly but continued almost linearly of the failure point (Fig 7 B) The curves of the last group were linear throughout or convex to the left (Fig 7 C) In the load range from 0 to five kp there was with few exceptions good agreement with the extended course and gradient of the curve Hence this portion of the curve was taken into account in classifying the types of curve shape

Slope of load elongation curves

The slope of the load elongation curve tan α was a qualitative but not quantitative characteristic of the material tested The tan α was calculated from a minimum applied load of five kp (reasons for this choice of starting point have been given previously) along the linear portion of the curve to the load applied at the point where the curve begins to level off In about 60 per cent of the diagrams the change in the slope of the curve occurred at a load of five kp but in the remaining 40 per cent it occurred at a slightly greater load

tan α was computed from the formula

$$\tan \alpha = \frac{\Sigma xy - \frac{\Sigma x \, \Sigma y}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}$$

where x is the numerical value of Δl in mm × 10 and y is that of P in kp for each point of measurement

The means of tan α values for the stored groups and the controls i e the 0 hour group are given in table 2 The statistical analysis was carried out as follows The means in the stored groups were compared by analysis of variance with the difference between groups and the difference between right and left knee assumed as important variates (Hald 1952) The results are given in table 3 and show that there are no significant differences between stored groups nor are the differen ces between right and left knee measurements significant The com parison of the mean of all stored groups with the mean of the controls by Student s t test showed that there were no significant differences in these means

Failure energy

The shaded area beneath the curve (Fig 4) represents the energy required to rupture the ligament The areas of these roughly triangu lar figures were measured with an Amsler planimeter (type 612)

Statistical analysis performed similarly to those applied to tan α shows no significant differences cf tables 2 and 3

A decline in failure energy in the series could be masked by an increase in body weights in the groups tested It is seen in tables 2 and 3 that there are no significant differences in body weights and this possibility was rejected as an explanation for the lack of change in the failure energy values

Failure load

The occurrence of an immediately total rupture of the test specimen is shown in the original recording (Fig 3) by an instantaneous drop of the load to 0 kp This occurred in most of the cases In some cases (30 per cent) the 0 kp level was restored in a succession of *steps This* difference in the shape of the curve beyond the rupture point bears no relation to the rupture site Mean absolute failure loads are shown in Table 2 No correlation with the weight of the animal was found in the

0 hour group (Kendall and Stuart 1958) Statistical analysis of the failure load performed in the same way as those applied to tan α reveals

GROUP	n	MEAN VALUES (± standard error)				
		tan α	Failure energy kpmm	Failure load kp	Failure elongation mm	Body weight kg
Stored 2 hrs	8	1 40 ± 0 10	44 5 ± 4 6	30 6 ± 1 3	2 06 ± 0 15	3 57
6	8	1 37 ± 0 14	65 7 ± 11 9	31 1 ± 2 9	2 77 ± 0 31	3 73
24	8	1 21 ± 0 16	47 0 ± 8 6	29 6 ± 1 7	2 39 ± 0 31	3 48
48	8	1 42 ± 0 15	38 2 ± 4 1	30 4 ± 2 1	2 03 ± 0 15	3 41
96	8	1 37 ± 0 09	49 5 ± 8 0	30 4 ± 1 5	2 19 ± 0 22	2 67
All stored groups	40	1 36 ± 0 05	49 0 ± 3 5	30 2 ± 1 0	2 29 ± 0 12	3 37
Controls (fresh)	14	1 53 ± 0 07	36 0 ± 5 9	26 9 ± 1 1	1 74 ± 0 07	2 80
Diff all stored and contr		0 17	13 0	3 3	0 55	0 57
t test of diff		1 46	1 83	1 74	1 25	1 72

Table 2 Main table for tan α failure energy failure load and elongation at failure

Parameter	Source of var	df	Sum of squares	Mean square	F
tan a	Between groups	4	[illegible]	0 0719	1 08
	Right vs left knee	5	[illegible]	[illegible]	< 1
	Remainder	30	4 2012	0 1192	
	TOTAL	39	[illegible]		
Failure energy (kpmm)	Between groups	4	[illegible]	839 96	[illegible]
	Right vs left knee	5	[illegible]	437 92	< 1
	Remainder	30	[illegible]	517 52	
	TOTAL	39	[illegible]		
Failure load (kp)	Between groups	4	29 09	7 27	< 1
	Right vs left knee	5	48 13	9 63	< 1
	Remainder	30	[illegible]	39 90	
	TOTAL	39	1136 97		
Failure elongation (mm)	Between groups	4	2 9818	[illegible]	[illegible]
	Right vs left knee	5	2 1794	[illegible]	< 1
	Remainder	30	[illegible]	[illegible]	
	TOTAL	39	21 1637		
Body weight (kg) all groups	Between groups	5	3 7724	[illegible]	2 4
	Within groups	18	[illegible]	[illegible]	
	TOTAL	23	9 2619		

Table 3 Analysis of variance to the parameters in table 2

no indication of any relationship between this load and time of storage cf tables 2 and 3

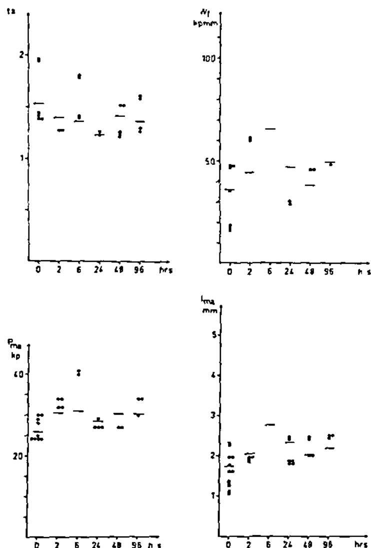


Fig 8 The individual values of tan α failure energy failure load and elongation at failure in the different time groups — denotes the mean value of a parameter in a time group

Elongation at rupture

Mean absolute elongation values at the rupture point are shown in table 2 Statistical analysis was performed in the same way as those applied to tan α and revealed no indication of any relationship beween this elongation and time of storage cf tables 2 and 3

Dips in curve

Some of the load curves recorded during the tests show at various intervals a slight drop in the load after which the curve resumes its previous slope. Such drops of 0.5 kp or more were designated »dips«. The frequency of dips and their mean magnitude in each time group are given in table 4.

Analysis of variance is applicable to the dip frequency only with caution (Scheffe 1959). If the analysis is performed (cf. tables 4 5) it reveals no significant difference between the stored groups but the mean of all stored groups is significantly higher than that of the con

Time group (hours postmortem)	No. of curves	No. of dips	Frequency per curve	Magnitude in kp		
				min	mean	max
2	8	6	1.1	0.5	1.9	5
6	8	12	1.5	0.5	1.9	9
6 (augmented)	16	23	1.4	0.5	1.4	6
24	8	10	1.3	0.5	2.1	9
48	8	8	1.0	0.5	1.3	4
96	8	5	0.8	0.5	1.1	2
All stored groups	40	44	1.1	0.5	1.8	9
Controls	14	9	0.4	0.5	1.1	2
Diff. all stored and controls			0.7			
t test of diff.			2.66*			

Table 4. Frequency of dips in the curves and their magnitude
* denotes significance

trols Even though this difference exists comparison of the individual stored groups to the control group by Wilcoxen s method (1945) shows that only the 6 hour group value is significantly higher than that of the controls This significance persists when the 6 hour group is doubled This set of significant and non significant results cannot definitively be evaluated here It is probable that the difference between the stored groups and the controls was due to chance, since no trend could be established

The mean dip magnitude is still less suitable for a statistical analysis

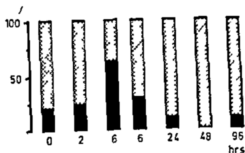
Parameter	Source of var	df	Sum of squares	Mean square	F
Frequency of dips	Between groups	4	3 35	0 84	< 1
	Right vs left knee	5	7 75	1 55	< 1
	Remainder	30	38 50	0 84	
	TOTAL	39			

Table 5 Analysis of variance to the frequency of dips

Site of rupture

The bone ligament bone complexes usually (in about 80 per cent of the cases) ruptured either as a result of the tearing away of a piece of bone varying in size from a tiny chip to the greater part of the femoral or tibial condyle or failure of the ligament itself Whilst the former type actually are fractures—usually called tear off fractures—the latter constitute true ligament ruptures The rupture site distribution within time groups is shown in Fig 9 and table 6

Here the Fischer Irwin test (Lehmann 1959) was used to compare the frequency of the ligament ruptures in the stored groups one by one to the control group It is noteworthy that there are many ligament ruptures in the original 6 hour group but this is not the case with the enlarged 6 hour group Yet no significant differences could be found between the 0 hour group and the other groups even if the observations from the same animal were considered independent



Group	Lig.	Bone			[illegible]
		femur	tibia	Total	
Stored 2 hrs	2	0	6	[illegible]	02
6	[illegible]	1	2	3	0[illegible]
6 (aug)	[illegible]	1	10	11	031
24	1	0	7	7	01[illegible]
48	0	1	7	8	0[illegible]
96	1	3	4	7	013
Controls	3	1	10	11	013

Table 6 Rupture sites in the femur anterior cruciate ligament tibia preparations

HISTOLOGY

Literature

It was established long ago that ligaments and tendons are composed of collagenous fibres disposed in bundles paralleling the direction of stretch which are separated by rows of fibrocytes In transverse sections through a ligament the fibrocytes are endowed with a stellate shape by their processes which insinuate themselves between the bundles of fibres Near the attachments to bone the fibrocytes become rounded and encapsulated and the amount of amorphous intercellular substance increases considerably Such views have been published by Hardy (1951) Smith (1954) and Vas (1959) Ham and Leeson (1961) review the subject in their textbook of histology

Methods

Immediately after their excision the ligaments were fixed in 10 per cent formalin solution If in the case of anterior cruciate ligaments subjected to tensile strength testing bone fragments had been detached together with the ligament the entire preparation was decalcified in a mixture of equal volumes of concentrated formic acid and 7 per cent sodium formate solution The formalin fixed and decalcified preparation was rinsed in water and dehydrated by passing through solutions of 70 per cent to 100 per cent ethanol and lastly into methyl benzoate After pre treatment with xylene the preparation was embedded in paraffin and cut into five μ sections which were stained by Delafield s haematoxylineosine procedure

Results

The histological part of the present investigation was commenced with a comparison between the posterior and anterior cruciate ligaments in the 0 hour group Their histological pictures exhibit no conclusive differences The following account of the normal appearances refers to the posterior ligament which has not been subjected to tensile strength tests

The histological appearance of the ligaments in the various time groups is not always unequivocal the degree of the changes varying widely both between ligaments within groups and between groups Thus for example sections of almost normal appearance are some e ncountered in ligaments fixed long after death The comments

given below summarize those changes ... sections in each time group

The ligaments in the *0 hour group* ... fibres disposed in parallel bundles separ... Towards its attachments the ligament conta... ground substance the cells are more round... tute a stage intermediate between fibrocytes a... In transverse sections the fibrocytes lod... collagenous bundles and present a punctate ... (Fig 11) This agrees well with observations ... workers

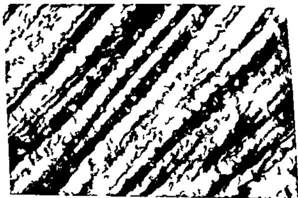


Fig 10 L... li n fi... mentous attachm... ... frocyt... c n titute ... mediate ... tes and ch... (240x)

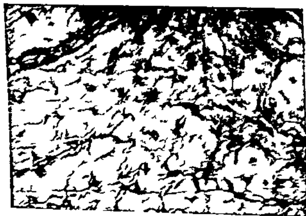


Fig 11 Transverse ... tion of normal ligam... ous tissue showing c... genous fibres dispo... regular bundles with ... bocytes between them. (788x)

In the *2 hour group* the collagenous bundles seem swollen and exhibit numerous patches with especially in transverse sections a structureless hyalinized appearance Less sharply demarcated from one another than in the 0 hour group the bundles seem less coherent Though the majority of cells have a normal appearance some of them are larger and rounder than those in the 0 hour group (Fig 12)

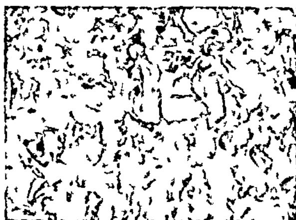


Fig 12 Transverse section of a ligament in the 2 hour group illustrating the structureless and hyalinized appearance of the collagenous bundles and some larger fibrocytes in addition to those of normal size and shape (288x)

The *6 hour group* is not conspicuously different from the 2 hour group In addition to similar structureless patches the collagenous fibres are more evident

In the *24 hour group* the changes continue with blurring of the collagenous bundles which are spaced further apart Some cell nuclei in occasional sections exhibit abnormally poor staining properties but others are heavily stained A few nuclei disintegrate into even more heavily stained fragments (Fig 13)

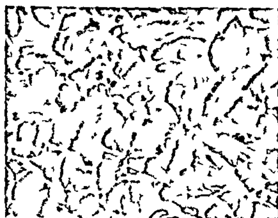


Fig 13 Transverse section of a ligament in the 24 hour group showing poor cohesion between collagenous bundles and varying stainability of fibrocyte nuclei (288x)

The most characteristic feature in the *48 hour group* is the low nuclei content in extensive parts of the preparation This is particularly apparent in transverse sections which occasionally present no cell structures other than small heavily stained nuclear remnants (Fig 14)



Fig 14 Transverse section of a ligament in the 48 hour group illustrating paucity of cell nuclei and varying nuclear stainability (288x)

The most extensive changes with patches of totally decomposed and completely structureless tissue a few deformed nuclear remnants and large spaces traversing the preparation are encountered in the *96 hour group*

Summing up the changes seen in the several groups increase with time after death In the main these changes are apparently due to autolysis which gives rise to progressive blurring of structures in the collagenous bundles and decomposition of the cells The autolytic changes in the ligamentous ground substance also seem to impair the cohesion of the collagenous bundles So far as could be determined by the technique employed the individual fibres on the other hand are resistant to autolysis and consequently maintain their shape and structure throughout the period of observation

This agrees with the result of investigations on the preservation of tendon grafts Thus Herzog (1963) found the degeneration to begin with the cell nuclei and to proceed later in the interstitial tissue the collagenous fibres remaining intact

longer than an hour or two However most of those workers who have described their techniques mentioned that the ligaments were exposed to air unlike the case in the present investigation where they have remained in the intact and closed knee joint until the test was due to commence And in such circumstances as disclosed by our findings no changes of significance take place even after four days's storage at room temperature

SUMMARY

The present investigation was designed to reveal whether the mechanical properties and histological appearance of ligaments undergo postmortal changes by storage Such knowledge is of importance in mechanical studies on human autopsy material

The literature on the mechanical properties of ligaments and related tissues is surveyed particular attention being paid to published information concerning postmortal changes

In the present investigation sixty two intact anterior cruciate ligaments from rabbits were subjected to strength tests The test specimens consisting of the ligament with its femoral and tibial attachments were divided into six groups according to the number of hours between the death of the animal and testing Methods and apparatus are described and illustrated

The mechanical basis for the experiments and the analysis of the results is discussed

The results have been analysed with respect to the following factors (i) the gross shape of the load elongation curve (ii) the slope of these curves (iii) the area beneath these curves as a measure of the failure energy (iv) the failure load (v) elongation at failure (vi) dips in the curves and (vii) the rupture site on the bone ligament bone preparations

The analysis of the numerical material does not reveal evidence for any consistent changes with time

The ligaments were also studied histologically using standard methods The histological study of the ligaments discloses progressive blurring of the structure of the collagenous bundles combined with decomposition of cells and ground substance These changes are ascribed mainly to autolysis On the other hand the collagenous fibres proved highly resistant to autolytic changes

ZUSAMMENFASSUNG

In dieser Arbeit wurde untersucht inwieweit bei Verwahrung postmortale Veränderungen eintreten die die mechanischen Eigenschaften und das histologische Bild des Ligaments betreffen Das Wissen über dieses Verhalten ist von fundamentaler Bedeutung da man mechanische Studien an humanem Sektionsmaterial ausführen will

Eine Uebersicht der Literatur uber die mechanischen Eigenschaften der Ligamente und der naheliegenden Gewebe wird gegeben Besondere Beachtung wird dem was frühere Verfasser betreffs postmortaler Veränderungen gefunden haben geschenkt

In dieser Arbeit wurde intaktes Ligamentum cruciatum anterius mit Femur und Tibiaansats von erwachsenen Kaninchen studiert Das Material umfasst sechs Gruppen mit Aufbewahrung von null bis sechs und neunzig Stunden von der Tötung an bis zur Ausfuhrung des Versuchs Die Methodik und Apparatur wird beschrieben

Die grundlegenden Prinzipien und der mechanische Hintergrund zu den Experimenten sowie die Analysen der Resultate werden diskutiert

Folgende Faktoren wurden analysiert 1) die allgemeine Form der erhaltenen Spannungsdehnungskurven (load elongation) 2) die Inklinationskoeffizienten dieser Kurven 3) das Feld unter diesen Kurven sowie ein Mass von der Brechenergie 4) Bruchlast 5) Dehnung beim Bruch 6) Zacken (dips) in den Kurven und 7) die Rupturstelle des Knochen Ligament Knochen Präparats

Die Analyse des Zahlenmaterials hat kein Vorkommen von systematischen Veranderungen gezeigt die während der Zeit entstanden sind

Eine histologische Untersuchung der Ligamente wurde bei Verwendung von Standardmethoden ausgeführt Das mikroskopische Bild innerhalb der verschiedenen Zeitgruppen wird beschrieben Es zeigt eine fortschreitende Verschwommenheit in der Struktur der kollagenen Bundel sowie Auflosung der Zellen und Grundsubstanz Diese Veranderungen konnten hauptsachlich mit Autolyse erklart werden Die kollagenen Fibern dagegen haben sich als sehr resistent gegen autolytische Veranderungen erwiesen

longer than an hour or two However most of those workers who have described their techniques mentioned that the ligaments were exposed to air unlike the case in the present investigation where they have remained in the intact and closed knee joint until the test was due to commence And in such circumstances as disclosed by our findings no changes of significance take place even after four days storage at room temperature

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ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM No 80

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THE INFLUENCE OF HORMONAL TREATMENT AND ORCHIECTOMY, OOPHORECTOMY AND THYROIDECTOMY ON EXPERIMENTAL FRACTURES

A QUANTITATIVE P^{32} AUTORADIOGRAPHIC, ROENTGENOLOGIC AND TISSUE-ANALYTIC STUDY

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Translated by Uljas Attila M Sc

Printed in Finland
Helsinki 196[illegible]
KESKUSKIRJAPAINO

CONTENTS

I INTRODUCTION

Recent research has shown that endocrine factors play an important role among the biological agents affecting the regeneration of bone. Growth hormone in itself and particularly in combination with thyrotropin has been demonstrated to stimulate osteogenesis and to have a beneficial effect on the rate of bone repair, while cortisone exerts an inhibitory effect (15, 17, 19, 32). A short time ago the osseous anabolic effect of growth hormone together with thyrotropin was also established in human fractures in which the consolidation tendency was poor (16). In these references the theoretical aspects of hormonal effects on bone repair and on the calcium and phosphorus metabolism have been considered in more detail. On the whole the significance of endocrine factors in fracture healing is receiving increasing attention (39, 40).

In contrast to the wide-spread administration of anabolic steroid hormones in the hope of promoting bone repair and shortening the patients' time of confinement, the results of investigation concerning the effect of such hormones are rather scanty and controversial, and the explanation they furnish of the matter is unsatisfactory. The results obtained in experimental studies with different animals are also at variance and little convincing.

In some experimental studies androgen hormone had no effect on the rate of fracture healing (1), while other authorities report that it was favourably influenced by sex hormones (3, 11, 12, 24). Recently adequate dosage of norandrosterone propionate has been found to further the healing of fractures and to produce a positive nitrogen

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A report of this study was presented at the Third European Symposium on Calcified Tissues, Davos 1965. This work has been aided by a grant from the Sigrid Juselius Foundation and by an institutional grant from the same Foundation to the Department of Forensic Medicine, University of Helsinki, which is gratefully acknowledged.

balance whereas massive doses caused retardation (25) The development of callus in animals has been observed to be more rapid when oestrogen was administered (13), while according to other results (29) the effect was doubtful and in another study (7) oestrogen slightly retarded the formation of callus Furthermore, inhibition of growth and increased endosteal formation of bone in the rat has been reported (36) Upon ovariectomy the callus formation as well as the breaking strength of the bones is stated to decrease (22) Thyroxine has been found to accelerate and cortisone (desoxycorticosterone) to depress the osteogenesis in experimental fractures (10)

In the way of methods the studies have often been based on mere descriptive observations Hardly any use has been made of quantitative methods in investigations concerning the effect of hormones or of hormonal deficiency

In the present attempt to clarify the effects of endocrine factors *the writer endeavoured to establish optimum conditions for systematic* quantitative elucidation of the subject The following approaches were enlisted to this end autoradiography with phosphorus 32 roentgenographic studies including planimetry of x rays and histoquantitative analysis The effect of androgen (19 norandrostenolone phenyl propionate) oestrogen (oestradiol monobenzoate) and thyroxine (DL β (3 5 diiodo 4 [3 5 diiodo 4 hydroxyphenoxy] phenyl) α aminopropionic acid) was investigated by administering the hormone in question and by removal of the testes ovaries and thyroid gland, respectively In addition to the thyroxine and thyroidectomy experiments also the effect of replacement therapy was studied by administering thyroxine to thyroidectomized animals

II MATERIAL AND METHODS

Experimental Animals and Groups

White rats of 150—210 g body weight were used in a total number of 220 animals including the controls namely, 145 males and 75 females All animals were given the same kind of food and were kept in uniform laboratory conditions

A closed complete fracture of the right tibia was caused to each rat and left to heal without fixation employing a previously established technique (15) Starting with the beginning of fracture healing part of the animals were given intramuscular injections of the substances mentioned in the introduction (p 6) while others were subjected to removal of endocrine glands at the occasion when the fracture was produced A third part of the material served as controls which were given physiological saline injections The animals were sacrificed after one to five weeks and subsequently treated as outlined in the next paragraph

Two deaths occurred within a few days of the gland removal These animals are not included in the series

The results recorded in the present studies were considered within the following groups

Androgen Group — Dosage 5 mg every second day sacrificed 7 14 21 28 and 35 days after the fracture five animals at each time for roentgenographic and histological studies Seven animals served the autoradiographic studies Their sacrificing dates coincided with the above mentioned times The group thus consists of 32 male animals

Oestrogen Group — Dosage 3 mg every second day five animals each sacrificed at the above mentioned times Seven rats for autoradiographic studies Total 32 female rats

Thyroxine Group — Dosage 0 3 mg every second day times of sacrificing as above Autoradiographic studies seven rats Altogether 32 male rats

balance whereas massive doses caused retardation (25) The development of callus in animals has been observed to be more rapid when oestrogen was administered (13) while according to other results (29) the effect was doubtful and in another study (7) oestrogen slightly retarded the formation of callus Furthermore inhibition of growth and increased endosteal formation of bone in the rat has been reported (30) Upon ovariectomy the callus formation as well as the breaking strength of the bones is stated to decrease (22) Thyroxine has been found to accelerate and cortisone (desoxycorticosterone) to depress the osteogenesis in experimental fractures (10)

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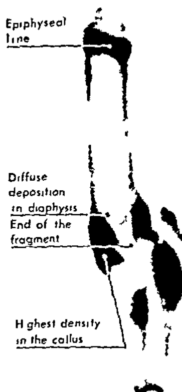


Fig 1 Autoradiograph (enlarged) produced from a longitudinal section through [illegible] fractured tibia illustrating the quantitative local variations of radio [illegible] deposition and the selection of points of d[illegible] tric measurement

repair process in each experimental group reproductions are [illegible] in this paper as Figs 3 6 and 8 which serve to illustrate the [illegible] graphic locations where radio phosphorus deposition occurred

The consolidation of each fracture was assessed using a [illegible] (0 — Poor callus 1 — Slight callus 2 — Fair callus 3 — Solid [illegible] callus) by visual examination of x rays taken after sacrifi[illegible] and [illegible] sidering also the simultaneous findings on palpation The ratin[illegible] averaged for each group and time of sacrificing

Paper prints at magnification 5× were made of the x ray and [illegible] area of the callus visible in them was determined using a [illegible]

Means were taken of the recorded areas (in mm^2 of the original x ray) for each group and sacrificing date

For histological examination and analysis of the callus components by the line sampling method decalcified preparations derived from the fracture sites were stained by the Pentachrom I and II methods (26)

As regards the detailed technique of the line sampling procedure reference is made to the writer's previous publication (15) and to its theoretical foundation (34 35) In brief the method implies that the fracture specimens are sectioned longitudinally through the centre of the medullary cavity of the fractured bone and a line is drawn from the end of the bone fragment at right angles to the shaft The intercepts of this line representing different tissue components of the callus (new bone, vascularization hyaline cartilage, fibrous cartilage fibrous tissue blood clot) are then recorded and the aggregated percentage of each component is plotted to produce a diagram illustrating conditions at the different stages of healing A special microprojector is used in this work The method has also been applied in studies of fracture healing during anticoagulant treatment (31)

III RESULTS

Controls

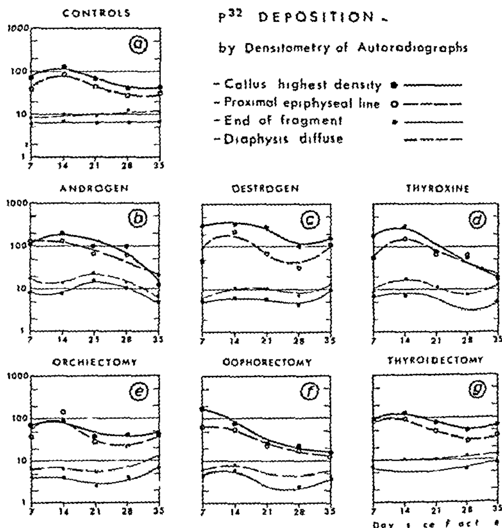


Fig 2 Results of densitometric evaluation of autoradiographs (cf Fig 1) in the control and test series reflecting the strength of phosphorus activity at specified sites in the callus and fractured bone during progress of the repair process

Ordinate values Relative amount of P^{32} accumulation within four hours of tracer injection

Histological Studies

Histological Findings Study of the microscopic slides revealed a similar general course of the fracture healing in male and female controls which did not differ from the previously described changes (15)

7 days after the fracture the area around the ends of the fragments is dominated by strong cell proliferation in fibrous connective tissue. The periosteum is thickened and the space between the outer surface of the fragment and the periosteal fibrous layer is filled with immature fibrous tissue. In the homogeneous structure occurs basophilously staining hyaline cartilage while osteoblasts are seen close to the diaphysis, part of them already cemented to the new bone that has been formed in the area between periosteum and outer diaphyseal surface. Many of the osteocytes at the ends of the fragments close to the fracture site are anuclear and the fragments are surrounded by a blood clot.

At 14 days the fragments are still surrounded by tissue rich in fibres and containing cells. The formation of new bone between periosteum and bone has increased; also endosteal formation of bone is observed. The area of new bone formation does not extend to the ends of the fragments.

21 days after the fracture a subperiosteal calcified callus is seen to have formed between the fragments and it is clearly demarcated from the connective tissue which is rich in cells. The new bone appears to be produced from hyaline cartilage but also from fibrous cartilage. At the same time cartilaginous cells dissolve, and the cavities formed in this manner become epithelium lined vascular spaces.

At 28 and 35 days trabecular formation of new bone is predominant, bridging the gap between the fragments both periosteally and endosteally. The lacunae at the ends of the fragments are empty even yet and there are signs of resorption of bone.

Line Sampling. The following trends are observable in the relative distribution of the different callus components on measurement by the histoquantitative line sampling procedure (Figs. 5 and 4c).

At the initial stage of the repair process, at seven days, the callus mainly consisted of fibrous tissue (70—80%). This tissue gradually decreased in the course of healing and ultimately vanished. At 14 days fibrous cartilage had appeared and also hyaline cartilage, the first mentioned constituting a considerable portion of the callus at this stage. From the third week onward new bone and concomitant vascularization are seen as new components, both increased in parallel while the immature tissue components diminished. Thus in the final stage the two kinds of tissue made up the matured callus together with a small quantity (less than 5%) of hyaline tissue.

Androgen and Orchiectomy

ANDROGEN

Phosphorus[3] Deposition

The levels of P[3] deposition noted in the callus in the androgen group at different times were mostly 40—50% above those in the controls except for the late stage at which the deposition fell below one half of the control value (Fig 2b) No such abrupt decline is seen in the values recorded for the epiphyseal line, which otherwise mostly remained below the values of the callus by about the same amount as in the controls

The deposition values relative to the end of the bone fragment and to the diffuse area of the diaphysis are somewhat elevated from the controls except for the late stage at which they fell below the controls too

Consolidation and Size of Callus

At 14 days examination of the x rays revealed distinct presence of callus, and the average degree of consolidation was better than 1 5 according to the 0—3 scale This indicates that the process was about one week ahead of that in the controls At 28 days the degree was close to 3 but at the end of the period of observation (after 35 days' androgen treatment) poorer consolidation (equivalent to average rating 2 0) was once more recorded (Fig 4a)

The size of callus determined by planimetry differed slightly from zero already at 7 days and increased at a high subsequently somewhat slower rate to about 15 mm² on the average at 35 days (25% higher than in the controls) (Fig 4b) It should be noted that the results of planimetry refer to the area of a longitudinal section of the callus If the measurements were evaluated in terms of actual mass of callus tissue, the latter parts of all curves would be raised and their initial portions suppressed

Histological Studies

Histological Findings Throughout the tests with animals under androgen hormone treatment the callus had progressed quite notably further in its development than in the controls at the corresponding

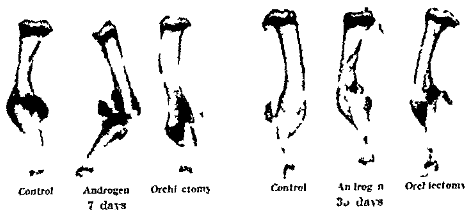


Fig 3 Autoradiographs of longitudinal sections through the fractured tibia at the early stage of the bone repair process (7 days on the left) and at its final stage (35 days on the right) in the control androgen and orchiectomy groups

times Considering the entire repair process the observation is made that the differentiation of cells and callus tissue which is characterized by osteoblast seams in the proliferating osteogenetic layer of the periosteum and the formation of new bone were markedly accelerated furnishing evidence of earlier maturation

At seven days the callus has great size and the histological picture is governed by powerful formation of hyaline cartilage New bone extends from deep in the area between periosteum and outer diaphyseal surface up to the ends of the fragments It is accompanied by profuse vascularization and incipient endosteal formation of new bone is also seen Fibrous tissue and fibrous cartilage occur scantily in the area around the fragments as well as residues of the blood clot The regenerative process shows no quantitative changes in respect of the callus components but closer study on the cellular level reveals that the cells of the mature cartilage tissue are hypertrophic and activated On comparison with the controls the histogenetic development of the callus can be said to have reached the same stage of maturity as that of the controls one week later at 14 days

At 14 days the periosteal formation of new bone is seen to have strengthened and there are bony trabeculae between the outer side of the cortical layer and the periosteum At 21 days the fragments are enveloped in a fairly continuous trabecular callus

At a distance from the ends of the fragments where the local condi

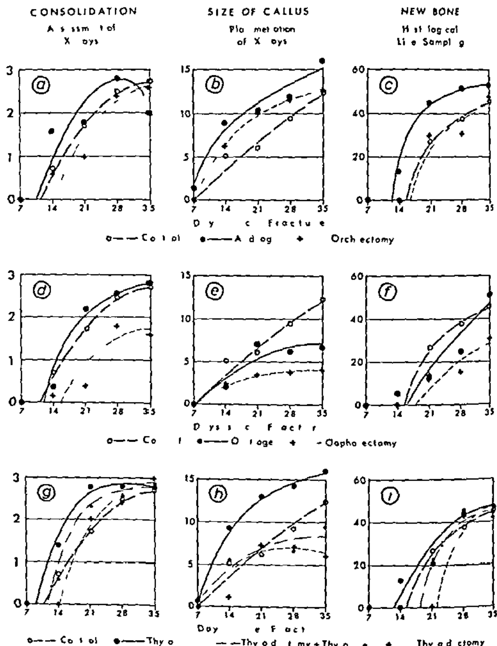


Fig 4 Results of studies elucidating consolidation development of callus and rate of formation of new bone in the control and test groups

Diagrams on the left — Degree of consolidation revealed by x rays and clinical palpation *Ordinates* Mean of ratings (maximum 3 0) cf p 9

Diagrams in the centre — Area of callus as seen in x rays means of five animals *Ordinates* Area in original x ray in mm²

Diagrams on the right — Amount of newly formed bone relative to total callus tissue according to histoquantitative analysis (cf Figs 5 7 and 9) *Ordinates* Percentage of new bone areas referred to total length of transect

tions of circulation are favourable formation of new bone seems to take place directly by osteoblast activity. In peripheral locations in the area around the ends of the fragments where there is posttraumatic vascular ischaemia the formation of new bone is by the intermediate phase of hyaline cartilage and also by transformation of fibrous cartilage into calcified cartilage and newly formed bone.

At 28 and 35 days the periosteal and endosteal formation of bone has become still stronger. At the same time resorption is seen to start at the ends of the bone fragments. It was evident on comparison with the controls that at this stage no longer any such differences in maturity of the callus can be demonstrated histologically as were strikingly manifest at the early stage of healing. In other words the untreated animals have by then largely caught up with the head start of those under androgen hormone treatment. This is borne out by the disappearance of immature tissue components from the histological picture presented by both groups.

Line Sampling (Fig. 5.) Analysis by the line sampling method with respect to the different callus components revealed that the callus of the animals under androgen hormone treatment contained at an early stage of repair (at 7 days) hyaline and fibrous cartilage and fibrous tissue. The last mentioned was present in small quantity (about 25%) and it became less and disappeared already before the end of the fourth week. In the course of progressing repair fibrous and hyaline tissue were replaced by formation of new bone and by its attendant vascularization already at an early stage — from the second week onward. In particular the new bone formation is seen to take place at an accelerated rate during the early half (first three weeks) of the healing period (see also Fig. 4c). While the callus of the controls contained more than 50% immature tissue components at this stage their percentage in the animals under androgen hormone treatment was less than 10%. Towards the end of the repair process the differences in tissue component distribution between the two groups tend to level out. The powerful predominance of mature components demonstrates that the differentiation has been speeded up by the effect of androgen hormone especially at an early stage

ORCHIECTOMY

Phosphorus[3] Deposition

The results of autoradiography describing the deposition of radio phosphorus in the callus area and on the epiphyseal line in the orchiectomy group are rather similar with those of the controls The diffuse deposition and that at the end of the fragment are seen to be lowered at the early stage of repair and most notably about the end of the third week (to one half) reverting to control level by the 35th day (Fig 2e)

Consolidation and Size of Callus

The orchiectomized animals displayed at 14 days a fair roentgenologically observable callus approximating that in the control group On the whole however the progress of consolidation seemed to be slightly retarded in comparison with the controls (Fig 4a) At the final stage (35 days) *the callus seen in the x ray though indicating satisfactory* consolidation was less dense The structure of the bone on the whole suggested osteoporosis

The development of callus size (Fig 4b) is intermediate between that in the androgen treated animals and in the controls

Histological Studies

Histological Findings In the orchiectomized animals the fresh callus at seven days is seen to be made up by tissue which is comparatively rich in cells The cells are smaller and the interstitial matter is fibrillar in character In closer vicinity of the subperiosteal area the cells increase in size and the matrix becomes homogenous Close to the outer *surface of the fragments formation of new bone can be seen in a narrow* zone but it stops far from the fractured end of the host bone which is enclosed in a blood clot

At 14 days there is increased formation of new bone as in the androgen group at seven days but stopping short of the ends of the fragments The peripheral area contains ample immature cartilage tissue and fibrous tissue The hyaline tissue cells are frequently anuclear degenerated, and the impression is that although cartilage cells are plentiful their normal differentiation and calcification is delayed

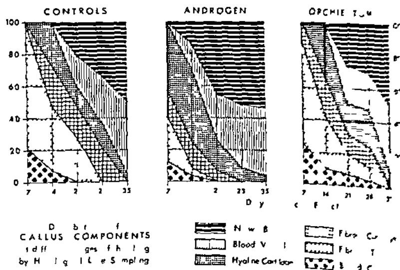


Fig 5 Histoquantitative tissue analysis diagrams showing th per cent position of the callus at different times after the fracture in the control and orchiectomy groups

At 21 days the callus has reached considerable size and the forma of bone has increased from what it was one week earlier Th calcified cartilage has likewise increased but there is still immature cell tissue left It is worth while to observe that compared to conditions under androgen hormone treatment the trabeculae of new bon irregular and thin and present osteoporotic appearance Immature tis persists in semblance of a seam in the periphery close to the ra periosteum

At 28 days the callus has decreased in size and its percenta of bone tissue has increased There is still fibrous tissue and fibrous cartila between the bone fragments

At 35 days the formation of new bone is seen to have increased both periosteally and endosteally In the middle between the fragments an area with immature callus extending up to the periosteum is noted These observations suggest that the regeneration of bone has been slightly disturbed at the initial stage of the repair process

Lane Sampling (Figs 5 and 4c) Histoquantitative study of the specimens derived from orchiectomized animals revealed that at the ea stage of healing the callus in the fracture area was mainly composed

fibrous tissue This tissue and likewise the blood clot persisted through out the repair process, becoming less and finally disappearing only at its very end The contribution of fibrous cartilage and hyaline cartilage to the callus was fairly constant from the beginning and throughout the process and the composition of the callus shows little deviation from that in the controls in this respect Formation of new bone and vascularization of the callus started after the second week and progressed at a fairly uniform rate to a final value virtually equal to that in the control and androgen groups

Oestrogen and Oophorectomy

OESTROGEN

Phosphorus[32] Deposition

The autoradiographs of the specimens in the oestrogen group (Fig 2c) reveal the most striking departure from the controls in that the deposition in the callus area was about four times that in the control group through out the repair process The deposition on the epiphyseal plate was not as greatly elevated The other two curves are approximately at control level

Consolidation and Size of Callus

Incipient callus formation is seen in the x rays of the oestrogen treated animals at 14 days after which the degree of consolidation pro gressed very rapidly above the rating 2 0 already at 21 days and coming close to 3 at the end of the period of observation (Fig 4d) In the x rays taken at this stage distinct sclerosis can be observed in the area around the ends of the fragments There are no signs of bone condensation *occurring in the marrow canal*

The growth of the callus in size (Fig 4e) according to the results of *planimetric study started after the 7th day* but proceeded at slow rate so that the area recorded at 35 days was no more than 7 mm² on the average i e only 60% of the corresponding figure in the control group

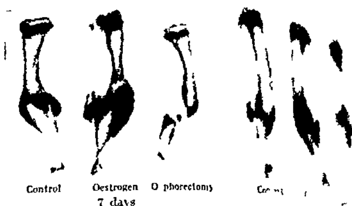


Fig 6 Autoradiographs of longitudinal sections the early stage of the bone repair process (7 days on the (35 days on the right) in the control oestrogen a

Histological Studies

Histological Findings At 7 days the call oestrogen hormone treatment consisted mainly of fibrous cartilage In the periosteal area close to the diaphysis incipient formation of new bone is obs far from the end of the fragment Hyaline cartil ends of the fragments are surrounded by a blood clot

At 14 days somewhat increased formation of new while the immature callus components are still ample is endosteal bone formation between the fragments sclerosis of the marrow are present Osteoblasts rather scanty The bone marrow is activated

At 21 days the development of the callus has status one week before although its appearance cell differentiation is disturbed and there are hyaline The formation of new bone starting deep in the extends far into the periphery and into the space around the fragments This area contains as characteristic component calcified cartilage between the fragments

At 28 days markedly increased formation of new bone the size of the callus is fairly small Its peripheral part contains cartilage and fibrous tissue and at the points where bone for

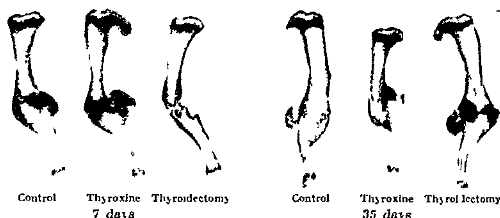


Fig 8 Autoradiographs of longitudinal sections through the fractured tibia at the early stage of the bone repair process (7 days on the left) and at its final stage (35 days on the right) in the control thyroxine and thyroidectomy groups

At 14 days the callus still contains fibrous tissue in ample amount and *immature cartilage but also hyaline cartilage The gap between the* fragments is even now filled with fibrous tissue and immature cartilage The formation of bone in the subperiosteal area has increased, and there is hyaline cartilage adjacent to the ends of the fragments The status is histologically evidently delayed in comparison to the control group

At 21 days increased formation of new bone is noted and the callus is fairly small There is still fibrous tissue and fibrous and hyaline car *tilage in the area around the ends of the fragments*

At 28 and 35 days the formation of new bone has further increased The trabecular formations are regular and accompanied by some vas cularization in the callus which is still quite small in size Incipient resorption is seen at the ends of the fragments At 35 days there still occurs a zone with fibrous tissue and fibrous and hyaline cartilage be tween the fragments

Line sampling (Figs 7 and 4f) The composition of the fracture callus found in the animals subjected to oophorectomy is different from all those treated in the foregoing in the respect that all types of tissue components *except the blood clot persist up to the final stage in the callus* develop ment

At the initial stage the contribution of fibrous tissue was strongly predominant its quantity decreased to about one third of this by the end of the second week The fibrous and hyaline cartilage components were otherwise dominant throughout the repair process, whereas new bone

its formation starting after 14 days was poorly represented all the t... The same is true for the vascularization of the callus ... the distribution of the callus components the relative predominance of ... tissues commenced at an early stage and continued throughout the process This indicates continuous disturbance of the differe... and maturation of the callus tissue

Thyroxine and Thyroidectomy

THYROXINE

Phosphorus[32] Deposition

Compared to the values recorded for the controls the ... data relating to the callus area in the specimens from thyroxine tre... animals agree fairly well with those found in the androgen group (F... The uptake at 7 days seems to be somewhat higher and so is the ... value at 35 days The densities measured on the epiphyseal line a... rather strongly scattered but seem to be consistent with the ... findings The end of fragment and diffuse diaphyseal depositions ... are rather similar as in the control group

Consolidation and Size of Callus

Consolidation was seen to be well under way at 14 days in the thy... roxine group, with a consolidation close to the rating 1 5 (Fig 4) Al... ready one week later the rating was as close to the maximum 3 ... rose in this group and as high as in the androgen group at its ... The dip at 35 days observed in the androgen group is absent here Some scl... rosis in the fracture area is evident in the x rays

The course of the callus size graph closely follows that in the andro... group during an early part of the period of observation but its ... continues at a good rate even when that of the androgen callus sl... down The ultimate value at 35 days is therefore slightly higher (Fi...

Histological Studies

Histological Findings At 7 days the animals treated with thy... roxine presented a callus of considerable size containing mainl...

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its formation starting after 14 days was poorly ... The same is true for the vascularization of the callus ... of the callus components the relative ... was commenced at an early stage and continued through ... This indicates continuous disturbance of the ... and maturation of the callus tissue

Thyroxine and Thyroidectomy

THYROXINE

Phosphorus[32] Deposition

Compared to the values recorded for the controls the ... data relating to the callus area in the specimens from thyroxine treated animals agree fairly well with those found in the androgen group (Fi... The uptake at 7 days seems to be somewhat higher and so is the lower value at 35 days. The densities measured on the epiphyseal line ... rather strongly scattered but seem to be consistent with the androgen findings. The end-of fragment and diffuse diaphyseal deposition curves are rather similar as in the control group

Consolidation and Size of Callus

Consolidation was seen to be well under way at 14 days in the thyroxine group with a consolidation close to the rating 1 5 (Fig 4g) ... nearly one week later the rating was as close to the maximum 3 0 as it rose in this group and as high as in the androgen group at its best. The dip at 35 days observed in the androgen group is absent here. Some sclerosis in the fracture area is evident in the x rays

The course of the callus size graph closely follows that in the androgen group during an early part of the period of observation but its ascent continues at a good rate even when that of the androgen callus slows down. The ultimate value at 35 days is therefore slightly higher (Fig 4h)

Histological Studies

Histological Findings At 7 days the animals treated with thyroxine presented a callus of considerable size containing ma...

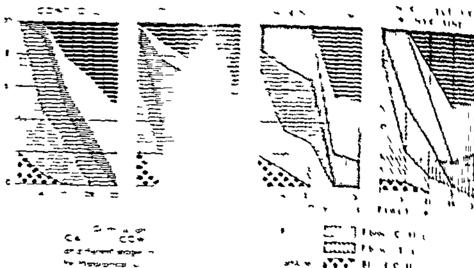


Fig. 2 H... position of the callus ... thyroxin ... ram ... howing the percent ... tra ture in the control thyroxin plus thyroxin groups

nearly coincident with ... of the graph and leve... quantities (Fig 2g) ... both in respect of character ... for the other two r...

Consolidation and Size of Callus

None of the x rays of thyroidectomized animals taken at 7 and 14 days revealed traces of callu... but at ... days the average degree of consolidation had reached the considerable value of 2.0. It continued to ... even further up to 3.0 at ... days (Fig. ...)

The average planimetric size ... little above 7 mm²; this level was already reached on the 21st day after the fracture (Fig. ...)

Histological Studies

Histological Findings At 7 days the callus is seen to contain great amounts of immature tissue components ... fibrous tissue and fibrous cartilage. The hyaline cartilage cells are small and the formation of new bone has its site deep under the detached periosteum, close to

the outer surface of the diaphysis The blood clot persists at the end of the fragments

At 14 days, the components of the callus are still fibrous tissue and fibrous cartilage and some quantity of hyaline cartilage The formation of new bone is poor throughout The development of the callus is clearly retarded

At 21 days the callus still contains much fibrous tissue and there is no sign of new bone between the fragments

At 28 and 35 days the immature tissues have subsided and been replaced by a callus with bone trabeculae bridging the gap between the fragments The trabeculae are rather thin and irregularly arranged the callus is fairly large There is some cartilage tissue left

Line Sampling (Figs 9 and 41) The line sampling measurements reveal that the early callus is composed of fibrous tissue and fibrous and hyaline cartilage At 21 days these components were present in fairly equal amounts, while fibrous tissue and fibrous cartilage disappeared by the time of 28 days At 35 days there was still hyaline tissue left A striking feature is the late appearance of new bone in the picture presented by the callus New bone does not occur before the fourth week subsequently at the final stage the callus was made up of new bone, new blood vessels and nearly 20% of hyaline cartilage

THYROIDECTOMY PLUS THYROXINE

Consolidation and Size of Callus

Examination of the x rays taken at 14 days in the group in which replacement thyroxine treatment was given to thyroidectomized rats revealed a slight amount of callus (Fig 4g) During the next week quite rapid progress of consolidation brought its average degree up above 2 0 The ultimate status did not differ from that in the controls or in the thyroxine group, the density of the bone was as in the controls

In respect of callus size according to planimetric study the initial course of the graph obtained in the thyroidectomy group seems to be reproduced here up to the time of 21 days (Fig 4h) Subsequently the is some further rise while the 35 day value remains half way betw the thyroidectomy and control plots

Histological Studies

Histological Findings In the experiments involving both thyroidectomy and treatment with thyroxine the callus present at seven days contains fibrous tissue fibrous and hyaline cartilage and in the subperiosteal area formation of new bone which does not reach the end of the fragment There is a fair number of osteoblasts A blood clot surrounds the fragments

At 14 days the callus displays considerable formation of hyaline cartilage there is some fibrous cartilage and fibrous tissue between the fragments the apposition of which is good The formation of new bone has progressed quite far though not up to the end of the fragment The maturation of the callus has progressed farther than at the equivalent time in the thyroidectomized animals histologically the status is even superior to that seen in the controls

At 21 days the formation of new bone has increased and the bone extends to the fracture area bridging the gap Hyaline cartilage is left in the peripheral area and a zone of fibrous cartilage and fibrous tissue is seen between the fragments

At 28 and 35 days a fairly large osseous callus is seen periosteally and endosteally There is a little fibrous tissue and hyaline cartilage in the space between the fragments

Line Sampling (Figs 9 and 41) Histoquantitative study revealed the callus at seven days to consist mainly of fibrous tissue some fibrous cartilage and incipient formation of hyaline cartilage are encountered in addition The relative quantity of immature tissue components is slightly less than in the controls indicating somewhat accelerated maturation On the other hand the quantity of hyaline cartilage is somewhat greater throughout the period of observation The formation of new bone is equivalent to that in the development of callus in the controls At the final stage the quantity of new bone is slightly less as is that of new blood vessels

The persistent presence of hyaline cartilage and its fairly constant percentage throughout the period of observation is similar to the corresponding phenomenon in the thyroidectomy group while it was seen in even stronger degree in the oophorectomized animals

kinetic analysis (4) has been used to demonstrate inhibition of resorption by oestrogen to which the endosteal bone formation is attributed rather than to growth promoting function (36)

In the present study no mineral deposition in the medullary cavity was observed Instead the accumulation of P^{32} in the callus was strikingly elevated under oestrogen treatment, indicating its increased mineral content The histological examination revealed high density and thickness of the bone trabeculae while the osteoclasts were rather few Roentgenographically sclerosis could be seen at the ends of the fragments and the callus was small These peculiarities became more pronounced with continued oestrogen therapy The observations made in respect of this *group are consistent with the concept that the ossification* promoting effect of oestrogen involves reduced resorption of bone as a particular characteristic of its calcifying action

No such over mineralization as in the oestrogen group was evident in the oophorectomized rats On the contrary the autoradiographs revealed a strong decline of the deposition during the progress of repair Assessment of the x rays disclosed delayed consolidation between the fragments and the callus *size determined by planimetry of the x rays* was minimal in fact rather consistently only one half of that in the oestrogen group at the corresponding times No readily obvious cause for this phenomenon suggests itself on the strength of existing knowledge

The effects elicited by androgen administration in experimental fractures are commonly attributed to the proteo anabolic action which this *hormone* evokes *in the protein matrix of the* bone and which leads to calcification (11) In the present study the influence of androgen manifested itself in rapid maturation of the *callus characterized by early* formation of new bone and vascularization The callus, which was large on the strength of the planimetric studies displayed elevated P^{32} deposition, though with a marked decreasing tendency towards the end of the observation period It may also be noted that the assessment of consolidation at 35 days gave a poorer rating than in the control series and also inferior to that recorded in the androgen group at 28 days *This might be speculatively associated with previously reported similar* effects of relatively high androgen dosage (1)

The densitometric measurements of autoradiographs while serving the purpose of elucidating the course of fracture repair under the effect of endocrine agents or their deficiency enable also observations to be

made concerning the accumulation of the labelled mineral substance in the epiphyseal plate at the ends of the bone fragments and in diffuse distribution in the diaphysis at a distance from the fragment end

The high densities appearing in the autoradiographs as areas of intense blackening have long been associated with new bone mineralization (8 14 15) In contrast the diffuse darkening is thought to be connected mainly with the portion of the bone consisting of exchangeable matter

The densitometrically measured values referring to the strongest blackening in the callus region on one hand and to the epiphyseal plate on the other as well as those found for the end of the fragment and for the diffuse deposition in the diaphysis seem to be very closely correlated and from their relations some inferences may be possible with regard to the mineralization during progress of bone repair

The values showing the uptake of phosphorus in the callus though varying within considerably wide limits in the different hormone administration and ectomy groups are invariably higher than the corresponding data found for the epiphyseal plate Both varied in the same manner during the observation period Variations of largely similar character have been reported in studies concerning the normal healing of fractures (21 38) The deposition at the end of the fragment was smallest of all in every set of four values and quite far below the deposition in the callus These values are slightly but constantly exceeded by the diffuse deposition in the diaphysis This indicates that the osteones of the devitalized end of the bone are inactive and unable to initiate the regeneration

If the present results are evaluated from a general point of view it must be noted that no claim of their general validity can be made without further consideration nor is it safe to extrapolate from them directly to the effects of endocrines in human bone repair However it has been clearly demonstrated that these hormones which one has not considered to possess targets with obvious bearing on bone (27 28) as exemplified particularly by androgen with its effect on the nitrogen balance exert an influence which enables the biological phenomenon involved in bone repair to be controlled to a certain extent Further research may be able to show the value of these agents as aids in the treatment of certain kinds of cases in which it is desired to simulate the regeneration of bone Opportunities for such studies are presented by numerous diseases of the bone with endocrine aetiology and by bone injuries occurring in association with them

V SUMMARY

Investigations concerning the repair of experimental fractures of the tibia under hormonal treatment or hormonal deficiencies were carried out with the aid of densitometric measurement of autoradiographs, augmented by roentgenological observations both visual and planimetric and by histological and histoquantitative studies

The quantitative autoradiograph evaluating method by which data were obtained on the relative strengths of the radio phosphorus deposition occurring at different times in the callus area at the epiphyseal line at the end of the bone fragment and diffusely in the diaphysis proved to be instructive, furnishing information on the amount and development of mineralization under the different experimental conditions during the progress of fracture repair With few exceptions, the P^{32} uptake correlated fairly well with the results of the roentgenographic and histo quantitative studies

The highest density in the autoradiographs was regularly seen in the callus area the values representing the isotope accumulation at the epiphyseal line being lower by about 30% The diffuse deposition in the diaphysis and the uptake at the end of the fragment were in a lower order of magnitude about one fifth of the first mentioned values The mineralization at the end of the fragment was consistently lower than that indicated by the diffuse diaphyseal deposition

In the callus area a marked increase in radiophosphorus uptake (40–50%) was noted at the early stage of bone regeneration under the effect of androgen and also of thyroxine treatment Largely similar results were recorded in both respective experimental groups as regards mineralization and the uptake also declined in both groups to the control level or somewhat below at the end of the observation period

The action of oestrogen revealed itself in a most striking deposition of radio phosphorus exceeding that in the controls by a factor of about 4 In contrast to all other experimental groups moreover, the uptake re

mained at an elevated level throughout the repair process It is suggested that the phenomenon is due to calcifying action of the hormone enhanced by reduced resorption of bone

Orchiectomy and thyroidectomy were found to have fairly slight influence on the bone repair process The values indicating phosphorus activity at the fracture site coincided with the control level On removal of the thyroid gland however the results of histoquantitative tissue analysis give evidence of delay at the early stage of repair in the cell differentiation involved in the maturation of the newly formed bone

Upon oophorectomy a falling tendency of the phosphorus deposition in the callus prevailed throughout the period of observation The value recorded at the final stage of the repair process was only about one half of the control level

In the discussion the contribution of endocrines as biological factors influencing the regeneration of bone is considered The need of further research is stressed by which an accurate idea might be formed of the beneficial effects in man that can be derived from hormones

VI ZUSAMMENFASSUNG

Es sind Versuche betreffs der Knochenheilung bei experimenteller Tibiafraktur unter Hormonbehandlung bzw. Hormonmangel angestellt worden, wobei densitometrische Messungen an Autoradiogrammen durch sowohl visuelle als auch planimetrische rontgenologische Beobachtungen sowie histologische und histoquantitative Untersuchungen erganzt wurden.

Die angewandte quantitative Methode zur Auswertung der Autoradiogramme, mittels welcher Angaben uber die relative Starke der zu verschiedenen Zeiten im Bereich des Kallus, an der Epiphysengrenze, am Ende des Knochenfragments sowie diffus in der Diaphyse stattfindenden Deposition von radioaktivem Phosphor gewonnen wurden, erwies sich als instruktiv, indem sie Aufschluss uber Betrag und Entwicklung der Mineralisation unter den verschiedenen Experimentalverhaltnissen im Verlauf des Reparaturprozesses lieferte. Mit wenigen Ausnahmen wies der P^{32}-Niederschlag recht gute Korrelation mit den Ergebnissen der zusatzlichen rontgenographischen und histoquantitativen Studien auf.

Die grosste Dichte in den Autoradiogrammen wurde regelmassig im Bereich des Kallus wahrgenommen, wahrend die Werte fur die Anreicherung der Isotope an der Epiphysengrenze um etwa 30% niedriger lagen. Der diffuse Niederschlag in der Diaphyse und die Aufnahme am Ende des Fragments waren geringerer Grossenordnung, etwa ein Funftel der erstgenannten Werte. Die Aktivitat der Mineralisation am Fragmentende war durchgehend niedriger als die durch die diaphysare Deposition angezeigte.

Im Kallusbereich wurde eine merkliche Steigerung der Phosphoraufnahme (um 40—50%) im zeitigen Stadium der Knochenregeneration unter Einfluss von Androgen und auch bei Thyroxintherapie beobachtet. In beiden Versuchsgruppen wurden weitgehend ubereinstimmende Ergebnisse bezuglich der Mineralisation verzeichnet, desgleichen ging die

Phosphoraufnahme in beiden Gruppen am Ende der Beobachtungsperiode auf Kontrollhöhe oder etwas weiter herab.

Die Wirkung von Oestrogen äusserte sich in einer sehr auffallenden Deposition von radioaktivem Phosphor, die Kontrollwerte etwa vierfach übertreffend. Im Gegensatz zu allen übrigen Versuchsgruppen hielt sich ferner hier die Aufnahme während der gesamten Dauer des Reparaturprozesses auf gesteigerter Höhe. Es wird geltend gemacht, dass die Erscheinung auf [illegible] Wirkung des Hormons, durch herabgesetzte Knochenresorption unterstützt, beruhen kann.

Bei Orchiektomie und Oophorektomie wurde recht wenig Einfluss auf den Knochenreparationsprozess festgestellt. Die Werte, welche die Phosphoraktivität am Frakturort anzeigen, fielen mit dem Spiegel bei den Kontrollen zusammen. Die Ergebnisse der histoquantitativen Gewebeanalyse nach Entfernung der Schilddrüse zeigten allerdings von einem Verzug der beim Reifen des neugebildeten Knochengewebes wesentlichen [illegible] im zweiten Stadium des Reparaturvorganges.

Nach ausgeführter Oophorektomie bestand eine fallende Tendenz der [illegible] während der gesamten Beobachtungsperiode. Im Endstadium des Reparaturprozesses wurde ein Wert verzeichnet, der nur der halben Höhe bei den Kontrollen gleichkommt.

In der Besprechung wird der Beitrag der endokrinen Drüsen und ihrer Sekretionen als biologische Faktoren im Einfluss auf die Knochenregeneration berührt. Die Notwendigkeit weiterer Forschungsarbeit wird betont, um einen zutreffenden Begriff von den günstigen Wirkungen zu erhalten, die diese Hormone im Menschen erzielt werden können.

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RÉSUMÉ

L'étude présente était destinée à faire voir si les propriétés mécaniques et la nature histologique des ligaments subissent des changements post mortem durant un procès de conservation. De telles connaissances sont importantes dans les études mécaniques sur la matière d'autopsie humaine.

La bibliographie sur les propriétés mécaniques des ligaments et des tissus apparentés a été étudiée en prêtant spécialement attention aux informations publiées concernant les changements post mortem.

Dans l'étude présente 62 ligaments cruciformes antérieurs intacts de lapins furent soumis à des épreuves de résistance. Les spécimens de l'étude formés du ligament et de ses liens fémoraux et tibiaux furent repartis en six groupes d'après le nombre d'heures écoulées entre la mort de l'animal et l'épreuve. Les méthodes et les appareils sont décrits et illustrés.

La base mécanique des expériences et l'analyse des résultats sont décrites.

Les résultats furent analysés en tenant compte des facteurs suivants:

1) la forme élémentaire de la courbe charge allongement
2) l'inclinaison de ces courbes
3) la surface au dessous de ces courbes comme mesure de l'énergie de défaut
4) la charge de défaut
5) l'allongement à la rupture
6) les points minimums des courbes
7) le point de rupture sur les préparations os ligament os

L'analyse du matériel numérique ne révèle aucune preuve de changements qui tiennent au temps.

Les changements furent aussi étudiés d'un point de vue histologique en utilisant des méthodes traditionnelles. L'étude histologique des ligaments révèle un obscurcissement progressif de la structure des faisceaux collagènes combiné avec une décomposition des cellules et de la substance de base. Ces changements sont surtout attribués à l'autolyse. D'un autre côté les fibres collagènes se montrèrent très résistantes aux changements autolytiques.

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